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(54) **AFFINITY MATURED CRlg VARIANTS**

AFFINITÄTSGEREIFTE CRlg-VARIANTEN

VARIANTS DE CRlg À MATURATION D’AFFINITÉ

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**Description**Field of the Invention

5 **[0001]** The present invention concerns affinity matured CRlg variants. In particular, the invention concerns CRlg variants having increased binding affinity to C3b and retaining selective binding to C3b over C3.

Background of the Invention10 The Complement System

**[0002]** The complement system is a complex enzyme cascade made up of a series of serum glycoproteins that normally exist in inactive, pro-enzyme form. Three main pathways, the classical, alternative and mannose-binding lectin pathway, can activate complement, which merge at the level of C3, where two similar C3 convertases cleave C3 into C3a and C3b.

15 **[0003]** Macrophages are specialist cells that have developed an innate capacity to recognize subtle differences in the structure of cell-surface expressed identification tags, so called molecular patterns (Taylor, et al., Eur J Immunol 33, 2090-1097 (2003); Taylor, et al., Annu Rev Immunol 23, 901-944 (2005)). While the direct recognition of these surface structures is a fundamental aspect of innate immunity, opsonization allows generic macrophage receptors to mediate engulfment, increasing the efficiency and diversifying recognition repertoire of the phagocyte (Stuart and Ezekowitz, 20 Immunity 22, 539-550 (2005)). The process of phagocytosis involves multiple ligand-receptor interactions, and it is now clear that various opsonins, including immunoglobulins, collectins, and complement components, guide the cellular activities required for pathogen internalization through interaction with macrophage cell surface receptors (reviewed by Aderem and Underhill, Annu Rev Immunol 17, 593-623 (1999); Underhill and Ozinsky, Annu Rev Immunol 20, 825-852 (2002)). While natural immunoglobulins encoded by germline genes can recognize a wide variety of pathogens, the majority of opsonizing IgG is generated through adaptive immunity, and therefore efficient clearance through Fc receptors is not immediate (Carroll, Nat Immunol 5, 981-986 (2004)). Complement, on the other hand, rapidly recognizes pathogen surface molecules and primes the particle for uptake by complement receptors (Brown, Infect Agents Dis 1, 63-70 (1991)).

25 **[0004]** Complement consists of over 30 serum proteins that opsonize a wide variety of pathogens for recognition by complement receptors. Depending on the initial trigger of the cascade, three pathways can be distinguished (reviewed by Walport, N Engl J Med 344, 1058-1066 (2001)). All three share the common step of activating the central component C3, but they differ according to the nature of recognition and the initial biochemical steps leading to C3 activation. The classical pathway is activated by antibodies bound to the pathogen surface, which in turn bind the C1q complement component, setting off a serine protease cascade that ultimately cleaves C3 to its active form, C3b. The lectin pathway is activated after recognition of carbohydrate motifs by lectin proteins. To date, three members of this pathway have 35 been identified: the mannose-binding lectins (MBL), the SIGN-R1 family of lectins and the ficolins (Pyz et al., Ann Med 38, 242-251 (2006)). Both MBL and ficolins are associated with serine proteases, which act like C1 in the classical pathway, activating components C2 and C4 leading to the central C3 step. The alternative pathway contrasts with both the classical and lectin pathways in that it is activated due to direct reaction of the internal C3 ester with recognition motifs on the pathogen surface. Initial C3 binding to an activating surface leads to rapid amplification of C3b deposition 40 through the action of the alternative pathway proteases Factor B and Factor D. Importantly, C3b deposited by either the classical or the lectin pathway also can lead to amplification of C3b deposition through the actions of Factors B and D. In all three pathways of complement activation, the pivotal step in opsonization is conversion of the component C3 to C3b. Cleavage of C3 by enzymes of the complement cascades exposes the thioester to nucleophilic attack, allowing covalent attachment of C3b onto antigen surfaces via the thioester domain. This is the initial step in complement opsonization. Subsequent proteolysis of the bound C3b produces iC3b, C3c and C3dg, fragments that are recognized by 45 different receptors (Ross and Medof, Adv Immunol 37, 217-267 (1985)). This cleavage abolishes the ability of C3b to further amplify C3b deposition and activate the late components of the complement cascade, including the membrane attack complex, capable of direct membrane damage. However, macrophage phagocytic receptors recognize C3b and its fragments preferentially; due to the versatility of the ester-bond formation, C3-mediated opsonization is central to pathogen recognition (Holers et al., Immunol Today 13, 231-236 (1992)), and receptors for the various C3 degradation products therefore play an important role in the host immune response.

50 **[0005]** C3 itself is a complex and flexible protein consisting of 13 distinct domains. The core of the molecule is made up of 8 so-called macroglobulin (MG) domains, which constitute the tightly packed  $\alpha$  and  $\beta$  chains of C3. Inserted into this structure are CUB (C1r/C1s, Uegf and Bone morphogenetic protein-1) and TED domains, the latter containing the thioester bond that allows covalent association of C3b with pathogen surfaces. The remaining domains contain C3a or act as linkers and spacers of the core domains. Comparison of C3b and C3c structures to C3 demonstrate that the molecule undergoes major conformational rearrangements with each proteolysis, which exposes not only the TED, but additional new surfaces of the molecule that can interact with cellular receptors (Janssen and Gros, Mol Immunol 44,

3-10 (2007)).

*Complement C3 Receptors on Phagocytic Cells*

**[0006]** There are three known gene superfamilies of complement receptors: The short consensus repeat (SCR) modules that code for CR1 and CR2, the beta-2 integrin family members CR3 and CR4, and the immunoglobulin Ig-superfamily member CR1g.

**[0007]** CR1 is a 180-210 kDa glycoprotein consisting of 30 Short Consensus Repeats (SCRs) and plays a major role in immune complex clearance. SCRs are modular structures of about 60 amino acids, each with two pairs of disulfide bonds providing structural rigidity. High affinity binding to both C3b and C4b occurs through two distinct sites, each composed of 3 SCRs reviewed by (Krych-Goldberg and Atkinson, Immunol Rev 180, 112-122 (2001)). The structure of the C3b binding site, contained within SCR 15-17 of CR1 (site 2), has been determined by MRI (Smith et al., Cell 108, 769-780 (2002)), revealing that the three modules are in an extended head-to-tail arrangement with flexibility at the 16-17 junction. Structure-guided mutagenesis identified a positively charged surface region on module 15 that is critical for C4b binding. This patch, together with basic side chains of module 16 exposed on the same face of CR1, is required for C3b binding. The main function of CR1, first described as an immune adherence receptor (Rothman et al., J Immunol 115, 1312-1315 (1975)), is to capture ICs on erythrocytes for transport and clearance by the liver (Taylor et al., Clin Immunol Immunopathol 82, 49-59 (1997)). There is a role in phagocytosis for CR1 on neutrophils, but not in tissue macrophages (Sengelov et al., J Immunol 153, 804-810 (1994)). In addition to its role in clearance of immune complexes, CR1 is a potent inhibitor of both classical and alternative pathway activation through its interaction with the respective convertases (Krych-Goldberg and Atkinson, 2001, *supra*; Krych-Goldberg et al., J Biol Chem 274, 31160-31168 (1999)). In the mouse, CR1 and CR2 are two products of the same gene formed by alternative splicing and are primarily associated with B-lymphocytes and follicular dendritic cells and function mainly in regulating B-cell responses (Molina et al., 1996). The mouse functional equivalent of CR1, Crry, inactivates the classical and alternative pathway enzymes and acts as an intrinsic regulator of complement activation rather than as a phagocytic receptor (Molina et al., Proc Natl Acad Sci USA 93, 3357-3361 (1992)).

**[0008]** CR2 (CD21) binds iC3b and C3dg and is the principal complement receptor that enhances B cell immunity (Carroll, Nat Immunol 5, 981-986 (2004); Weis et al., Proc Natl Acad Sci USA 81, 881-885 (1984)). Uptake of C3d-coated antigen by cognate B cells results in an enhanced signal via the B cell antigen receptor. Thus, coengagement of the CD21-CD19-CD81 coreceptor with B cell antigen receptor lowers the threshold of B cell activation and provides an important survival signal (Matsumoto et al., J Exp Med 173, 55-64 (1991)). The CR2 binding site on iC3b has been mapped partly on the interface between the TED and the MG1 domains (Clemenza and Isenman, J Immunol 165, 3839-3848 (2000)).

**[0009]** CR3 and CR4 are transmembrane heterodimers composed of an alpha subunit (CD11b or  $\alpha_M$  and CD11c or  $\alpha_X$ , respectively) and a common beta chain (CD 18 or  $\beta_2$ ), and are involved in adhesion to extracellular matrix and to other cells as well as in recognition of iC3b. They belong to the integrin family and perform functions not only in phagocytosis, but also in leukocyte trafficking and migration, synapse formation and costimulation (reviewed by (Ross, Adv Immunol 37, 217-267 (2000)). Integrin adhesiveness is regulated through a process called inside-out signaling, transforming the integrins from a low- to a high-affinity binding state (Liddington and Ginsberg, J Cell Biol 158, 833-839 (2002)). In addition, ligand binding transduces signals from the extracellular domain to the cytoplasm. The binding sites of iC3b have been mapped to several domains on the alpha chain of CR3 and CR4 (Diamond et al., J Cell Biol 120, 1031-1043 (1993); Li and Zhang, J Biol Chem 278, 34395-34402 (2003); Xiong and Zhang, J Biol Chem 278, 34395-34402 (2001)). The multiple ligands for CR3: iC3b, beta-glucan and ICAM-1, seem to bind to partially overlapping sites contained within the I domain of CD11b (Balsam et al., 1998; Diamond et al., 1990; Zhang and Plow, 1996). Its specific recognition of the proteolytically inactivated form of C3b, iC3b, is predicted based on structural studies that locate the CR3 binding sites to residues that become exposed upon unfolding of the CUB domain in C3b (Nishida et al., Proc Natl Acad Sci U S A 103, 19737-19742 (2006)), which occurs upon  $\alpha'$  chain cleavage by the complement regulatory protease, Factor I.

**[0010]** CR1g is a macrophage associated receptor with homology to A33 antigen and JAM1 that is required for the clearance of pathogens from the blood stream. A human CR1g protein was first cloned from a human fetal cDNA library using degenerate primers recognizing conserved Ig domains of human JAM1. Sequencing of several clones revealed an open reading frame of 400 amino acids. Blast searches confirmed similarity to Z39Ig, a type 1 transmembrane protein (Langnaese et al., Biochim Biophys Acta 1492 (2000) 522-525). The extracellular region of this molecule was found to consist of two Ig-like domains, comprising an N-terminal V-set domain and a C-terminal C2-set domain. The novel human protein was originally designated as a "single transmembrane Ig superfamily member macrophage associated" (huSTIgMA). (huSTIgMA). Subsequently, using 3' and 5' primers, a splice variant of huSTIgMA was cloned, which lacks the membrane proximal IgC domain and is 50 amino acids shorter. Accordingly, the shorter splice variant of this human protein was designated huSTIgMAshort. The amino acid sequence of huSTIgMA (referred to as PRO362) and the encoding polynucleotide sequence are disclosed in U.S. Patent No. 6,410,708, issued June 25, 2002. In addition, both

huSTIgMA and huSTIgMAshort, along with the murine STIgMA (muSTIgMA) protein and nucleic acid sequences, are disclosed in PCT Publication WO 2004031105, published April 15, 2004.

**[0011]** The crystal structure of CRIg and a C3b:CRIg complex is disclosed in U.S. Application Publication No. 2008/0045697, published February 21, 2008. The structure of this complex is also described in Wiesmann et al., Nature, 444(7116):217-20, 2006. This paper also describes the use of CRIg mutants to provide evidence that CRIg acts as an inhibitor of the alternative complement pathway. Furthermore, PCT Publication WO 2008036135 concerns the use of the CRIg and C3b:CRIg complex structures to identify molecules that are structurally and functionally related to CRIg.

**[0012]** The Kupffer cells (KCs), residing within the lumen of the liver sinusoids, form the largest population of macrophages in the body. Although KCs have markers in common with other tissue resident macrophages, they perform specialized functions geared towards efficient clearance of gut-derived bacteria, microbial debris, bacterial endotoxins, immune complexes and dead cells present in portal vein blood draining from the microvascular system of the digestive tract (Bilzer et al., Liver Int 26, 1175-1186 (2006)). Efficient binding of pathogens to the KC surface is a crucial step in the first-line immune defense against pathogens (Benacerraf et al., J Exp Med 110, 27-48 (1959)). A central role for KCs in the rapid clearance of pathogens from the circulation is illustrated by the significantly increased mortality in mice depleted of KCs (Hirakata et al., Infect Immun 59, 289-294 (1991)). The identification of CRIg further stresses the critical role of complement and KCs in the first line immune defense against circulating pathogens. The use of CRIg in the prevention and treatment of complement-associated disorders has been described in PCT Publication WO 2006042329.

**[0013]** The only complement C3 receptors identified on mouse KCs are CRIg and CR3 (Helmy et al., Cell 124, 915-927 (2006)), while human KCs show additional expression of CR1 and CR4 (Hinglais et al., 1989). Both CRIg and CR3 on KCs contribute to binding to iC3b opsonized particles in vitro (Helmy et al., Lab Invest 61, 509-514 (2006)). In vivo, a role of KC-expressed CR3 in the binding to iC3b-coated pathogens is less clear. CR3 has been proposed to contribute to clearance of pathogens indirectly via recruitment of neutrophils and interaction with neutrophil-expressed ICAM1 (Conlan and North, Exp Med 179, 259-268 (1994); Ebe et al., Pathol Int 49, 519-532 (1999); Gregory et al., J Immunol 157, 2514-2520 (1996); Gregory and Wing, J Leukoc Biol 72, 239-248 (2002); Rogers and Unanue, Infect Immun 61, 5090-5096 (1993)). In contrast, CRIg performs a direct role by capturing pathogens that transit through the liver sinusoidal lumen (Helmy et al., 2006, *supra*). A difference in the biology of CRIg vs CR3 is in part reflected by difference in binding characteristics of these two receptors. CRIg expressed on KCs constitutively binds to monomeric C3 fragments whereas CR3 only binds to iC3b-opsonized particles (Helmy et al., 2006, *supra*). The capacity of CRIg to efficiently capture monomeric C3b and iC3b as well as C3b/iC3b-coated particles reflects the increased avidity created by a multivalent interaction between CRIg molecules concentrated at the tip of membrane extensions of macrophages (Helmy et al., 2006, *supra*) and multimers of C3b and iC3b present on the pathogen surface. While CR3 only binds iC3b-coated particles, CRIg additionally bind to C3b, the first C3 cleavage product formed on serum-opsonized pathogens (Croize et al., Infect Immun 61, 5134-5139 (1993)). Since a large number of C3b molecules bound to the pathogen surface are protected from cleavage by factor H and I (Gordon et al., J Infect Dis 157, 697-704 (1988)), recognition of C3b ligands by CRIg ensures rapid binding and clearance. Thus, while both CRIg and CR3 are expressed on KCs, they show different ligand specificity, distinct binding properties and distinct kinetics of pathogen clearance.

**[0014]** Examples of pathogens that exploit cell surface receptors for cellular entry are viruses like human immunodeficiency virus (HIV), and intracellular bacteria like *Mycobacterium tuberculosis*, *Mycobacterium leprae*, *Yersinia pseudotuberculosis*, *Salmonella typhimurium* and *Listeria Monocytogenes* and parasites like the prostigmatoid *Leishmania major* (Cossart and Sansonetti, Science 304:242-248 (2004); Galan, Cell 103:363-366 (2000); Horne et al., Nat. Immunol. 3:1033-1040 (2002); Stoiber et al., Mol. Immunol. 42:153-160 (2005)).

**[0015]** As discussed above, CRIg is a recently discovered complement C3 receptor expressed on a subpopulation of tissue resident macrophages. Next to functioning as a complement receptor for C3 proteins, the extracellular IgV domain of CRIg selectively inhibits the alternative pathway of complement by binding to C3b and inhibiting proteolytic activation of C3 and C5. However, CRIg binding affinity for the convertase subunit C3b is low (IC<sub>50</sub> > 1  $\mu$ M) requiring a relatively high concentration of protein to reach near complete complement inhibition. Accordingly, there is a need for CRIg polypeptides with improved therapeutic efficacy. The present invention provides such polypeptides.

#### Summary of the Invention

**[0016]** The present invention is based, at least in part, on the construction of a CRIg variant with enhanced binding affinity. A CRIg-ECD protein with combined amino acid substitutions Q64R and M86Y showed a 30 fold increased binding affinity and a 7 fold improved complement inhibitory activity over the wildtype CRIg variant. In addition, treatment with the affinity-improved CRIg fusion protein in a mouse model of arthritis resulted in a significant reduction in clinical scores compared to treatment with a wild-type CRIg protein

**[0017]** Accordingly, the present invention concerns CRIg variants, all as defined by the claims. In one aspect, the invention concerns a CRIg variant comprising an amino acid substitution at one or more amino acid positions selected from the group consisting of positions 8, 14, 18, 42, 44, 45, 60, 64, 86, 99, 105, and 110 in the amino acid sequence of

SEQ ID NO: 2, which has at least 2-fold increased binding affinity to C3b over native sequence human CRlg of SEQ ID NO: 2, and/or which is at least a 2-fold more potent inhibitor of the alternative complement pathway than native sequence human CRlg of SEQ ID NO: 2.

**[0018]** In one embodiment, the variant selectively binds to C3b over C3, or a fragment thereof.

**[0019]** In another embodiment, the binding affinity is increased by at least 3 fold, or by at least 4 fold, or by at least 5 fold, or by at least 6 fold, or by at least 7 fold, or by at least 9 fold, or by at least 10 fold, or by at least 15 fold, or by at least 20 fold, or by at least 30 fold, or by at least 40 fold, or by at least 50 fold, or by at least 70 fold, or by at least 80 fold, or by at least 90 fold, or by at least 100 fold.

**[0020]** In a further embodiment, the variant comprises an amino acid substitution at one or more of amino acid positions 60, 64, 86, 99, 105 and 110 in the amino acid sequence of SEQ ID NO: 2.

**[0021]** In an additional embodiment, the variant comprises one or more substitutions selected from the group consisting of E8W, W14F, E8Y /W14F; P45F; G42D/D44H/P45F; Q60I; Q64R; Q60I/Q64R; M86Y; M86W, M86F, M86W/Q99R; M86F/Q99R; K110D, K110 N; Q105R/K110N; Q105R/K110Q; and Q105K/K110D.

**[0022]** In another embodiment, the variant comprises one or more substitutions selected from the group consisting of Q64R/M86Y; Q60I/Q64R/E8Y; Q60I/Q64R/G42D; Q60I/Q64R/P45F; Q60I/Q64R/G42D/D44H/P45F; Q60I/Q64R/M86Y; Q60I/Q64R/Q105R; Q60I/Q64R/Q105K; Q60I/Q64R/K110N; Q60I/Q105R/K110N; M86Y/E8Y; M86Y/G42D/D44H/P45F; M86Y/P45F; M86Y/G42D/D44H/P45F; and M86Y/Q99R/M86Y/Q105R/M86Y/Q105K/M86Y/Q105R/K110N.

**[0023]** In yet another embodiment, the variant comprises one or more substitutions selected from the group consisting of Q60I; Q64R; Q60I/Q64R; M86Y; Q99L; Q105K/K110D; E8W/Q105R/K110N; Q64R/M86Y; Q60I/Q64R/E8Y; Q60I/Q64R/G42D; Q60I/Q64R/P45F; Q60I/Q64R/G42D/D44H/P45F; Q60I/Q64R/M86Y; Q60I/Q64R/Q105R; Q60I/Q64R/Q105K; Q60I/Q64R/K110N; M86Y/P45F; and M86Y/Q105K.

**[0024]** In a more specific embodiment, the variant comprises a Q60I/Q64R/M86Y or Q60I/Q64R/G42D/D44H/P45F substitution.

**[0025]** In another aspect, the invention concerns a chimeric molecule comprising a CRlg variant as defined herein.

**[0026]** In one embodiment, the chimeric molecule is an immunoadhesin.

**[0027]** In another embodiment, the immunoadhesin comprises a CRlg variant that is shorter than the full-length CRlg of SEQ ID NO: 2.

**[0028]** In yet another embodiment, the chimeric molecule comprises a CRlg extracellular domain.

**[0029]** In a further aspect, the invention concerns a pharmaceutical composition comprising a CRlg variant or a chimeric molecule, e.g. an immunoadhesin of the present invention, in admixture with a pharmaceutically acceptable excipient.

**[0030]** In a still further aspect, the invention concerns the CRlg variant, chimeric molecule, or immunoadhesin, for use in a method of medical treatment. In one embodiment the variant, chimeric molecule, or immunoadhesin is for use in a method for the prevention or treatment of a complement-associated disease or condition.

**[0031]** In one embodiment, the complement-associated disease is an inflammatory disease or an autoimmune disease.

**[0032]** In another embodiment, the complement-associated disease is selected from the group consisting of rheumatoid arthritis (RA), adult respiratory distress syndrome (ARDS), remote tissue injury after ischemia and reperfusion, complement activation during cardiopulmonary bypass surgery, dermatomyositis, pemphigus, lupus nephritis and resultant glomerulonephritis and vasculitis, cardiopulmonary bypass, cardioplegia-induced coronary endothelial dysfunction, type II membranoproliferative glomerulonephritis, IgA nephropathy, acute renal failure, cryoglobulinemia, antiphospholipid syndrome, age-related macular degeneration, uveitis, diabetic retinopathy, allo-transplantation, hyperacute rejection, hemodialysis, chronic occlusive pulmonary distress syndrome (COPD), asthma, aspiration pneumonia, urticaria, chronic idiopathic urticaria, hemolytic uremic syndrome, endometriosis, cardiogenic shock, ischemia reperfusion injury, and multiple sclerosis (MS).

**[0033]** In yet another embodiment, the complement-associated disease is selected from the group consisting of inflammatory bowel disease (IBD), systemic lupus erythematosus, rheumatoid arthritis, juvenile chronic arthritis, spondyloarthropathies, systemic sclerosis (scleroderma), idiopathic inflammatory myopathies (dermatomyositis, polymyositis), Sjogren's syndrome, systemic vaculitis, sarcoidosis, autoimmune hemolytic anemia (immune pancytopenia, paroxysmal nocturnal hemoglobinuria), autoimmune thrombocytopenia (idiopathic thrombocytopenic purpura, immune-mediated thrombocytopenia), thyroiditis (Grave's disease, Hashimoto's thyroiditis, juvenile lymphocytic thyroiditis, atrophic thyroiditis), diabetes mellitus, immune-mediated renal disease (glomerulonephritis, tubulointerstitial nephritis), demyelinating diseases of the central and peripheral nervous systems such as multiple sclerosis, idiopathic polyneuropathy, hepatobiliary diseases such as infectious hepatitis (hepatitis A, B, C, D, E and other nonhepatotropic viruses), autoimmune chronic active hepatitis, primary biliary cirrhosis, granulomatous hepatitis, and sclerosing cholangitis, inflammatory and fibrotic lung diseases (e.g., cystic fibrosis), gluten-sensitive enteropathy, Whipple's disease, autoimmune or immune-mediated skin diseases including bullous skin diseases, erythema multiforme and contact dermatitis, psoriasis, allergic diseases of the lung such as eosinophilic pneumonia, idiopathic pulmonary fibrosis and hypersensitivity pneumonitis, transplantation associated diseases including graft rejection, graft-versus host disease, Alzheimer's disease, paroxysmal

nocturnal hemoglobinurea, hereditary angioedema, atherosclerosis and type II membranoproliferative glomerulonephritis.

**[0034]** In a preferred embodiment, the complement-associated disease is rheumatoid arthritis (RA).

**[0035]** In another preferred embodiment, the complement-associated disease is a complement-associated eye condition.

**[0036]** In a further embodiment, the complement-associated eye condition is selected from the group consisting of all stages of age-related macular degeneration (AMD), uveitis, diabetic and other ischemia-related retinopathies, endophthalmitis, and other intraocular neovascular diseases.

**[0037]** In a still further embodiment, the intraocular neovascular disease is selected from the group consisting of diabetic macular edema, pathological myopia, von Hippel-Lindau disease, histoplasmosis of the eye, Central Retinal Vein Occlusion (CRVO), corneal neovascularization, and retinal neovascularization.

**[0038]** In yet another embodiment, the complement-associated eye condition is selected from the group consisting of age-related macular degeneration (AMD), choroidal neovascularization (CNV), diabetic retinopathy (DR), and endophthalmitis, where AMD includes both wet and dry or atrophic AMD.

**[0039]** In one embodiment, the patient is a mammal, preferable a human.

**[0040]** Also described herein is a method for inhibition of the production of C3b complement fragment in a mammal comprising administering to said mammal an effective amount of a CRIg variant of the present invention, or an immunoadhesin comprising such variant.

**[0041]** Also described herein is a method for selective inhibition of the alternative complement pathway in a mammal, comprising administering to said mammal an effective amount of a CRIg variant of the present invention, or an immunoadhesin comprising such variant.

#### Brief Description of the Drawings

**[0042]**

Figures 1A-1B show the nucleotide and amino acid sequences of the 399-amino acid full-length long form of native human CRIg (huCRIg, SEQ ID NOS: 1 and 2, respectively).

Figures 2A-2B show the nucleotide and amino acid sequences of the 305-amino acid short form of native human CRIg (huCRIg-short, SEQ ID NOS: 3 and 4, respectively).

Figures 3A-3C show the nucleotide and amino acid sequences of the 280-amino acid native murine CRIg (muCRIg, SEQ ID NOS: 5 and 6, respectively).

Figure 4: Activity of CRIg mutants in binding assay and inhibition assay. Binding affinity for CRIg was measured as competitive displacement of C3b (A), and the biological activity was measured by a hemolysis inhibition assay. PUR10680 was wild-type control (red), RIL 41 (blue) and RL41 (green) were two mutants (B). (C) Stepwise optimization of the CRIg binding interface.

Figure 5: Correlation between competitive ELISA and hemolytic assay.

Figure 6: CRIg mutant Q64R/M86Y shows improved binding affinity by Biacore analysis. (A) SPR sensograms generated by injection of increasing concentrations of C3b over coated CRIg wt and CRIg Q64R M86Y proteins. B. Steady state analysis of the binding data indicates a K<sub>d</sub> of 0.2 micromolar for the Q64R / M86Y mutant and 1.1 micromolar for wild-type CRIg.

Figure 7: Affinity-improved CRIg remains selective for C3b. Alpha Screen competitive assay was utilized on purified C3 and C3b.

Figure 8: Improved complement inhibitory potency of CRIg Q64R M86Y compared to wildtype CRIg. (A) Complement inhibition by wild-type CRIg and CRIg Q46R M86Y were compared using an alternative pathway-selective hemolytic assay using rabbit red blood cells and C1q-depleted human serum. (B) Complement inhibition by wild-type CRIg and CRIg Q46R M86Y were compared using an ELISA-based alternative pathway assay with microwell plate-coated LPS and C1q-depleted human serum.

Figure 9: CRIg Q64R M86Y shows improved efficacy *in vivo* over CRIg WT.

(A) Clinical scores of mice injected with KRN serum and treated with various concentrations and versions of wild-type and affinity-matured recombinant human and mouse CRIg proteins. Data represent mean of 4-7 mice per group. (B) Scatter plots of clinical scores from individual mice at day 6 following serum transfer. (C) Hematoxylin and eosin-stained sections of mice treated with CRIg wt or CRIg Q64R M86Y 6 days following serum transfer. (D) Scatter plots of histological scores from mice treated with CRIg wt or CRIg Q64R M86Y 6 days following serum transfer.

Table 1: Phage libraries. Five soft-randomized libraries were designed to cover the contact area between

CRIg and C3b.

Table 2: Step-wise generation of higher affinity CRIg my phage display. Selected mutants of CRIg anti-C3b from the five soft-randomized libraries. Each panel shows clones that were selected from each library based on binding affinity to C3b. The sequence is denoted by the single-letter amino acid code. Each panel compares the individual mutants with the consensus and parent wild-type (WT) sequences. Residues are colored accordingly: blue - soft randomized position; gray - not randomized; yellow - the selected residues, which are different from wild-type (WT). Table 2 discloses SEQ ID NOS 21-63 and 63-67, respectively, in order of appearance.

Table 3: Comparison of binding affinities, determined by competitive ELISA, and *in vivo* hemolysis inhibition for selected mutants. Mutants with a greater than 5 fold increased in binding affinity or *in vivo* potency are shaded yellow.

Table 4: Comparison of binding affinity and *in vivo* hemolysis inhibition for second generation mutants (parent sequences shown in gray). Mutants with a greater than 5 fold increase over the parent mutant in binding affinity are highlighted in blue, mutants with a greater than 90 fold increase in binding affinity are highlighted in yellow. Similarly, mutants with greater *in vivo* potency than parent sequences are highlighted in orange.

## Detailed Description of the Invention

### I. Definitions

**[0043]** The terms "CRIg," "PRO362," "JAM4," and "STIgMA" are used interchangeably, and refer to native sequence and variant CRIg polypeptides.

**[0044]** A "native sequence" CRIg, is a polypeptide having the same amino acid sequence as a CRIg polypeptide derived from nature, regardless of its mode of preparation. Thus, native sequence CRIg can be isolated from nature or can be produced by recombinant and/or synthetic means. The term "native sequence CRIg", specifically encompasses naturally-occurring truncated or secreted forms of CRIg (e.g., an extracellular domain sequence), naturally-occurring variant forms (e.g., alternatively spliced forms) and naturally-occurring allelic variants of CRIg. Native sequence CRIg polypeptides specifically include the full-length 399 amino acids long human CRIg polypeptide of SEQ ID NO: 2 (huCRIg, shown in Figures 1A and 1B), with or without an N-terminal signal sequence, with or without the initiating methionine at position 1, and with or without any or all of the transmembrane domain at about amino acid positions 277 to 307 of SEQ ID NO: 2. In a further embodiment, the native sequence CRIg polypeptide is the 305-amino acid, short form of human CRIg (huCRIg-short, SEQ ID NO: 4, shown in Figures 2A and 2B), with or without an N-terminal signal sequence, with or without the initiating methionine at position 1, and with or without any or all of the transmembrane domain at about positions 183 to 213 of SEQ ID NO: 4. In a different embodiment, the native sequence CRIg polypeptide is a 280 amino acids long, full-length murine CRIg polypeptide of SEQ ID NO: 6 (muCRIg, shown in Figures 3A-3C), with or without an N-terminal signal sequence, with or without the initiating methionine at position 1, and with or without any or all of the transmembrane domain at about amino acid positions 181 to 211 of SEQ ID NO: 6. CRIg polypeptides of other non-human animals, including higher primates and mammals, are specifically included within this definition.

**[0045]** The CRIg "extracellular domain" or "ECD" refers to a form of the CRIg polypeptide, which is essentially free of the transmembrane and cytoplasmic domains of the respective full length molecules. Ordinarily, the CRIg ECD will have less than 1% of such transmembrane and/or cytoplasmic domains and preferably, will have less than 0.5% of such domains. CRIg ECD may comprise amino acid residues 1 or about 21 to X of SEQ ID NO: 2, 4, or 6, where X is any amino acid from about 271 to 281 in SEQ ID NO: 2, any amino acid from about 178 to 186 in SEQ ID NO: 4, and any amino acid from about 176 to 184 in SEQ ID NO: 6.

**[0046]** The term "CRIg variant," as used herein, means an active CRIg polypeptide as defined below having at least about 80% amino acid sequence identity to a native sequence CRIg polypeptide, including, without limitation, the full-length huCRIg (SEQ ID NO: 2), huCRIg-short (SEQ ID NO: 4), and muCRIg (SEQ ID NO: 6), each with or without the N-terminal initiating methionine, with or without the N-terminal signal sequence, with or without all or part of the transmembrane domain and with or without the intracellular domain. In a particular embodiment, the CRIg variant has at least about 80% amino acid sequence homology with the mature, full-length polypeptide from within the sequence of the sequence of SEQ ID NO: 2. In another embodiment, the CRIg variant has at least about 80% amino acid sequence homology with the mature, full-length polypeptide from within the sequence of SEQ ID NO: 4. In yet another embodiment, the CRIg variant has at least about 80% amino acid sequence homology with the mature, full-length polypeptide from within the sequence of SEQ ID NO: 6. Ordinarily, a CRIg variant will have at least about 80% amino acid sequence identity, or at least about 85% amino acid sequence identity, or at least about 90% amino acid sequence identity, or at least about 95% amino acid sequence identity, or at least about 98% amino acid sequence identity, or at least about 99% amino acid sequence identity with the mature amino acid sequence from within SEQ ID NO: 2, 4, or 6. Throughout



the description, including the examples, the term "wild-type" or "WT" refers to the mature full-length short form of human CRlg (CRlg(S)) (SEQ ID NO: 4), and the numbering of amino acid residues in the CRlg variants refers to the sequence of SEQ ID NO: 4

**[0047]** The CRlg variants of the present invention are CRlg agonists, as hereinafter defined. In particular, the CRlg variants herein maintain selective binding to C3b over C3, where "selective binding" is used to refer to binding to C3b and a lack of binding to C3. In addition, in a preferred embodiment, the CRlg variants of the present invention have increased binding affinity to C3b relative to a native sequence CRlg polypeptide, such as the human long form of CRlg (SEQ ID NO: 2). In various embodiments, the increase in binding affinity is at least about 2 fold, or at least about 3 fold, or at least about 4 fold, or at least about 5 fold, or at least about 6 fold, or at least about 7 fold, or at least about 8 fold, or at least about 9 fold, or at least about 10 fold, or at least about 15 fold, or at least about 20 fold, or at least about 25 fold, or at least about 30 fold, or at least about 35 fold, or at least about 40 fold, or at least about 45 fold, or at least about 50 fold, or at least about 55 fold, or at least about 60 fold, or at least about 65 fold, or at least about 70 fold, or at least about 75 fold, or at least about 80 fold, or at least about 85 fold, or at least about 90 fold, or at least about 95 fold, or at least about 100 fold, relative to the native sequence human CRlg polypeptide of SEQ ID NO: 2. In other embodiments, the increase in binding affinity to C3b relative to the native sequence human CRlg polypeptide of SEQ ID NO: 2 is about 5-10 fold, or about 5-15 fold, or about 5-20 fold, or about 5-25 fold, or about 5-25 fold, or about 5-30 fold, or about 5-35 fold, or about 5-40 fold, or about 5-45 fold, or about 5-50 fold, or about 5-55 fold, or about 5-60 fold, or about 5-65 fold, or about 5-70 fold, or about 5-75 fold, or about 5-80 fold, or about 5-85 fold, or about 5-90 fold, or about 5-95 fold, or about 5-100 fold.

**[0048]** "Percent (%) amino acid sequence identity" with respect to the CRlg variants herein is defined as the percentage of amino acid residues in a CRlg variant sequence that are identical with the amino acid residues in the native CRlg sequence to which they are compared, after aligning the sequences and introducing gaps, if necessary, to achieve the maximum percent sequence identity, and not considering any conservative substitutions as part of the sequence identity. For sequences that differ in length, percent sequence identity is determined relative to the longer sequence, along the full length of the longer sequences. Alignment for purposes of determining percent amino acid sequence identity can be achieved in various ways that are within the skill in the art, for instance, using publicly available computer software such as BLAST, BLAST-2, ALIGN or Megalign (DNASTAR) software. Those skilled in the art can determine appropriate parameters for measuring alignment, including any algorithms needed to achieve maximal alignment over the full length of the sequences being compared. Sequence identity is then calculated relative to the longer sequence, i.e. even if a shorter sequence shows 100% sequence identity with a portion of a longer sequence, the overall sequence identity will be less than 100%.

**[0049]** "Percent (%) nucleic acid sequence identity" with respect to the CRlg variant encoding sequences identified herein is defined as the percentage of nucleotides in a candidate sequence that are identical with the nucleotides in the CRlg variant encoding sequence, respectively, after aligning the sequences and introducing gaps, if necessary, to achieve the maximum percent sequence identity. Alignment for purposes of determining percent nucleic acid sequence identity can be achieved in various ways that are within the skill in the art, for instance, using publicly available computer software such as BLAST, BLAST-2, ALIGN or Megalign (DNASTAR) software. Those skilled in the art can determine appropriate parameters for measuring alignment, including any algorithms needed to achieve maximal alignment over the full length of the sequences being compared. Sequence identity is then calculated relative to the longer sequence, i.e. even if a shorter sequence shows 100% sequence identity with a portion of a longer sequence, the overall sequence identity will be less than 100%.

**[0050]** Included in the definition of a CRlg variant are all amino acid sequence variants, as hereinabove defined, regardless of their mode of identification or preparation. Specifically included herein are variants that have been modified by substitution, chemically, enzymatically, or by other appropriate means with a moiety other than a naturally occurring amino acid, as long as they retain a qualitative biological property of a native sequence CRlg. Exemplary non-naturally occurring amino acid substitution include those described herein below.

**[0051]** Amino acid residues are classified into four major groups:

Acidic: The residue has a negative charge due to loss of H ion at physiological pH and the residue is attracted by aqueous solution so as to seek the surface positions in the conformation of a peptide in which it is contained when the peptide is in aqueous solution.

Basic: The residue has a positive charge due to association with H ion at physiological pH and the residue is attracted by aqueous solution so as to seek the surface positions in the conformation of a peptide in which it is contained when the peptide is in aqueous medium at physiological pH.

Neutral/non-polar: The residues are not charged at physiological pH and the residue is repelled by aqueous solution so as to seek the inner positions in the conformation of a peptide in which it is contained when the peptide is in aqueous medium. These residues are also designated "hydrophobic residues."

Neutral/polar: The residues are not charged at physiological pH, but the residue is attracted by aqueous solution

so as to seek the outer positions in the conformation of a peptide in which it is contained when the peptide is in aqueous medium.

**[0052]** Amino acid residues can be further classified as cyclic or non-cyclic, aromatic or non aromatic with respect to their side chain groups these designations being commonplace to the skilled artisan.

**[0053]** Commonly encountered amino acids which are not encoded by the genetic code, include 2-amino adipic acid (Aad) for Glu and Asp; 2-aminopimelic acid (Apm) for Glu and Asp; 2-aminobutyric (Abu) acid for Met, Leu, and other aliphatic amino acids; 2-aminoheptanoic acid (Ahe) for Met, Leu and other aliphatic amino acids; 2-aminoisobutyric acid (Aib) for Gly; cyclohexylalanine (Cha) for Val, and Leu and Ile; homoarginine (Har) for Arg and Lys; 2,3-diaminopropionic acid (Dpr) for Lys, Arg and His; N-ethylglycine (EtGly) for Gly, Pro, and Ala; N-ethylglycine (EtGly) for Gly, Pro, and Ala; N-ethylasparagine (EtAsn) for Asn, and Gln; Hydroxyllysine (Hyl) for Lys; allohydroxyllysine (AHyl) for Lys; 3-(and 4)hydroxyproline (3Hyp, 4Hyp) for Pro, Ser, and Thr; allo-isoleucine (Alle) for Ile, Leu, and Val; .rho.-amidinophenylalanine for Ala; N-methylglycine (MeGly, sarcosine) for Gly, Pro, and Ala; N-methylisoleucine (Melle) for Ile; Norvaline (Nva) for Met and other aliphatic amino acids; Norleucine (Nle) for Met and other aliphatic amino acids; Ornithine (Orn) for Lys, Arg and His; Citrulline (Cit) and methionine sulfoxide (MSO) for Thr, Asn and Gln; N-methylphenylalanine (MePhe), trimethylphenylalanine, halo (F, Cl, Br, and I)phenylalanine, triflourylphenylalanine, for Phe.

**[0054]** As used herein, the term "immunoadhesin" designates antibody-like molecules which combine the binding specificity of a heterologous protein (an "adhesin") with the effector functions of immunoglobulin constant domains. Structurally, the immunoadhesins comprise a fusion of an amino acid sequence with the desired binding specificity which is other than the antigen recognition and binding site of an antibody (i.e., is "heterologous"), and an immunoglobulin constant domain sequence. The adhesin part of an immunoadhesin molecule typically is a contiguous amino acid sequence comprising at least the binding site of a receptor or a ligand. The immunoglobulin constant domain sequence in the immunoadhesin may be obtained from any immunoglobulin, such as IgG-1, IgG-2, IgG-3, or IgG-4 subtypes, IgA (including IgA-1 and IgA-2), IgE, IgD or IgM.

**[0055]** "Treatment" is an intervention performed with the intention of preventing the development or altering the pathology of a disorder. Accordingly, "treatment" refers to both therapeutic treatment and prophylactic or preventative measures. Those in need of treatment include those already with the disorder as well as those in which the disorder is to be prevented.

**[0056]** "Ameliorate" as used herein, is defined herein as to make better or improve.

**[0057]** The term "mammal" as used herein refers to any animal classified as a mammal, including, without limitation, humans, non-human primates, domestic and farm animals, and zoo, sports or pet animals such horses, pigs, cattle, dogs, cats and ferrets, *etc.* In a preferred embodiment of the invention, the mammal is a higher primate, most preferably human.

**[0058]** The term "complement-associated disease" is used herein in the broadest sense and includes all diseases and pathological conditions the pathogenesis of which involves abnormalities of the activation of the complement system, such as, for example, complement deficiencies. The term specifically include diseases and pathological conditions that benefit from the inhibition of C3 convertase. The term additionally includes diseases and pathological conditions that benefit from inhibition, including selective inhibition, of the alternative complement pathway. Complement-associated diseases include, without limitation, inflammatory diseases and autoimmune diseases, such as, for example, rheumatoid arthritis (RA), acute respiratory distress syndrome (ARDS), remote tissue injury after ischemia and reperfusion, complement activation during cardiopulmonary bypass surgery, dermatomyositis, pemphigus, lupus nephritis and resultant glomerulonephritis and vasculitis, cardiopulmonary bypass, cardioplegia-induced coronary endothelial dysfunction, type II membranoproliferative glomerulonephritis, IgA nephropathy, acute renal failure, cryoglobulemia, antiphospholipid syndrome, age-related macular degeneration, uveitis, diabetic retinopathy, allo-transplantation, hyperacute rejection, hemodialysis, chronic occlusive pulmonary distress syndrome (COPD), asthma, and aspiration pneumonia. In a preferred embodiment, the "complement-associated disease" is a disease in which the alternative pathway of complement plays a prominent role, including rheumatoid arthritis (RA), complement-associated eye conditions, such as age-related macular degeneration, antiphospholipid syndrome, intestinal and renal ischemia-reperfusion injury, and type II membranoproliferative glomerulonephritis.

**[0059]** The term "complement-associated eye condition" is used herein in the broadest sense and includes all eye conditions and diseases the pathology of which involves complement, including the classical and the alternative pathways, and in particular the alternative pathway of complement. Specifically included within this group are all eye conditions and diseases the associated with the alternative pathway, the occurrence, development, or progression of which can be controlled by the inhibition of the alternative pathway. Complement-associated eye conditions include, without limitation, macular degenerative diseases, such as all stages of age-related macular degeneration (AMD), including dry and wet (non-exudative and exudative) forms, choroidal neovascularization (CNV), uveitis, diabetic and other ischemia-related retinopathies, endophthalmitis, and other intraocular neovascular diseases, such as diabetic macular edema, pathological myopia, von Hippel-Lindau disease, histoplasmosis of the eye, Central Retinal Vein Occlusion (CRVO),

corneal neovascularization, and retinal neovascularization. A preferred group of complement-associated eye conditions includes age-related macular degeneration (AMD), including non-exudative (wet) and exudative (dry or atrophic) AMD, choroidal neovascularization (CNV), diabetic retinopathy (DR), and endophthalmitis.

**[0060]** The term "inflammatory disease" and "inflammatory disorder" are used interchangeably and mean a disease or disorder in which a component of the immune system of a mammal causes, mediates or otherwise contributes to an inflammatory response contributing to morbidity in the mammal. Also included are diseases in which reduction of the inflammatory response has an ameliorative effect on progression of the disease. Included within this term are immune-mediated inflammatory diseases, including autoimmune diseases.

**[0061]** The term "T-cell mediated" disease means a disease in which T cells directly or indirectly mediate or otherwise contribute to morbidity in a mammal. The T cell mediated disease may be associated with cell mediated effects, lymphokine mediated effects, etc. and even effects associated with B cells if the B cells are stimulated, for example, by the lymphokines secreted by T cells.

**[0062]** Examples of immune-related and inflammatory diseases, some of which are T cell mediated, include, without limitation, inflammatory bowel disease (IBD), systemic lupus erythematosus, rheumatoid arthritis, juvenile chronic arthritis, spondyloarthropathies, systemic sclerosis (scleroderma), idiopathic inflammatory myopathies (dermatomyositis, polymyositis), Sjogren's syndrome, systemic vasculitis, sarcoidosis, autoimmune hemolytic anemia (immune pancytopenia, paroxysmal nocturnal hemoglobinuria), autoimmune thrombocytopenia (idiopathic thrombocytopenic purpura, immune-mediated thrombocytopenia), thyroiditis (Grave's disease, Hashimoto's thyroiditis, juvenile lymphocytic thyroiditis, atrophic thyroiditis), diabetes mellitus, immune-mediated renal disease (glomerulonephritis, tubulointerstitial nephritis), demyelinating diseases of the central and peripheral nervous systems such as multiple sclerosis, idiopathic polyneuropathy, hepatobiliary diseases such as infectious hepatitis (hepatitis A, B, C, D, E and other nonhepatotropic viruses), autoimmune chronic active hepatitis, primary biliary cirrhosis, granulomatous hepatitis, and sclerosing cholangitis, inflammatory and fibrotic lung diseases (e.g., cystic fibrosis), gluten-sensitive enteropathy, Whipple's disease, autoimmune or immune-mediated skin diseases including bullous skin diseases, erythema multiforme and contact dermatitis, psoriasis, allergic diseases of the lung such as eosinophilic pneumonia, idiopathic pulmonary fibrosis and hypersensitivity pneumonitis, transplantation associated diseases including graft rejection, graft-versus host disease, Alzheimer's disease, and atherosclerosis.

**[0063]** Administration "in combination with" one or more further therapeutic agents includes simultaneous (concurrent) and consecutive administration in any order.

**[0064]** "Active" or "activity" in the context of variants of the CRIg polypeptides of the invention refers to form(s) of such polypeptides which retain the biological and/or immunological activities of a native or naturally-occurring polypeptide of the invention. A preferred biological activity is the ability to bind C3b, and/or to affect complement or complement activation, in particular to inhibit the alternative complement pathway and/or C3 convertase. Inhibition of C3 convertase can, for example, be measured by measuring the inhibition of C3 turnover in normal serum during collagen- or antibody-induced arthritis, or inhibition of C3 deposition in arthritic joints.

**[0065]** "Biological activity" in the context of a polypeptide that mimics CRIg biological activity refers, in part, to the ability of such molecules to bind C3b and/or to affect complement or complement activation, in particular, to inhibit the alternative complement pathway and/or C3 convertase.

**[0066]** The term CRIg "agonist" is used in the broadest sense, and includes any molecule that mimics a qualitative biological activity (as hereinabove defined) of a native sequence CRIg polypeptide.

**[0067]** "Operably linked" refers to juxtaposition such that the normal function of the components can be performed. Thus, a coding sequence "operably linked" to control sequences refers to a configuration wherein the coding sequence can be expressed under the control of these sequences and wherein the DNA sequences being linked are contiguous and, in the case of a secretory leader, contiguous and in reading phase. For example, DNA for a presequence or secretory leader is operably linked to DNA for a polypeptide if it is expressed as a preprotein that participates in the secretion of the polypeptide; a promoter or enhancer is operably linked to a coding sequence if it affects the transcription of the sequence; or a ribosome binding site is operably linked to a coding sequence if it is positioned so as to facilitate translation. Linking is accomplished by ligation at convenient restriction sites. If such sites do not exist, then synthetic oligonucleotide adaptors or linkers are used in accord with conventional practice.

**[0068]** "Control sequences" refer to DNA sequences necessary for the expression of an operably linked coding sequence in a particular host organism. The control sequences that are suitable for prokaryotes, for example, include a promoter, optionally an operator sequence, and a ribosome binding site. Eukaryotic cells are known to utilize promoters, polyadenylation signals, and enhancers.

**[0069]** "Expression system" refers to DNA sequences containing a desired coding sequence and control sequences in operable linkage, so that hosts transformed with these sequences are capable of producing the encoded proteins. To effect transformation, the expression system may be included on a vector; however, the relevant DNA may then also be integrated into the host chromosome.

**[0070]** As used herein, "cell," "cell line," and "cell culture" are used interchangeably and all such designations include

progeny. Thus, "transformants" or "transformed cells" includes the primary subject cell and cultures derived therefrom without regard for the number of transfers. It is also understood that all progeny may not be precisely identical in DNA content because deliberate or inadvertent mutations may occur. Mutant progeny that have the same functionality as screened for in the originally transformed cell are included. Where distinct designations are intended, it will be clear from the context.

**[0071]** "Plasmids" are designated by a lower case "p" preceded and/or followed by capital letters and/or numbers. The starting plasmids herein are commercially available, are publicly available on an unrestricted basis, or can be constructed from such available plasmids in accord with published procedures. In addition, other equivalent plasmids are known in the art and will be apparent to the ordinary artisan.

**[0072]** A "phage display library" is a protein expression library that expresses a collection of cloned protein sequences as fusions with a phage coat protein. Thus, the phrase "phage display library" refers herein to a collection of phage (e.g., filamentous phage) wherein the phage express an external (typically heterologous) protein. The external protein is free to interact with (bind to) other moieties with which the phage are contacted. Each phage displaying an external protein is a "member" of the phage display library.

**[0073]** The term "filamentous phage" refers to a viral particle capable of displaying a heterogenous polypeptide on its surface, and includes, without limitation, fl, fd, Pfl, and M13. The filamentous phage may contain a selectable marker such as tetracycline (e.g., "fd-tet"). Various filamentous phage display systems are well known to those of skill in the art (see, e.g., Zacher et al., *Gene*, 9:127-140 (1980), Smith et al., *Science*, 228:1315-1317 (1985); and Parmley and Smith, *Gene*, 73:305-318 (1988)).

**[0074]** The term "panning" is used to refer to the multiple rounds of screening process in identification and isolation of phages carrying compounds, such as antibodies, with high affinity and specificity to a target.

**[0075]** The phrase "conserved amino acid residues" is used to refer to amino acid residues that are identical between two or more amino acid sequences aligned with each other.

## II. Detailed Description

**[0076]** Complement is an important component of the innate and adaptive immune response, yet complement split products generated through activation of each of the three complement pathways (classical, alternative, and lectin) can cause inflammation and tissue destruction. Thus, uncontrolled complement activation due to the lack of appropriate complement regulation has been associated with various chronic inflammatory diseases. Dominant in this inflammatory cascade are the complement split products C3a and C5a that function as chemoattractant and activators of neutrophils and inflammatory macrophages via the C3a and C5a receptors (Mollnes, T.E., W.C. Song, and J.D. Lambris. 2002. Complement in inflammatory tissue damage and disease. *Trends Immunol.* 23:61-64).

**[0077]** CRIg is a recently discovered complement receptor, which is expressed on a subpopulation of tissue resident macrophages. As a functional receptor, the extracellular IgV domain of CRIg is a selective inhibitor of the alternative pathway of complement (Wiesmann et al., *Nature*, 444(7116):217-20, 2006). A soluble form of CRIg has been shown to reverse inflammation and bone loss in experimental models of arthritis by inhibiting the alternative pathway of complement in the joint. It has also been shown that the alternative pathway of complement is not only required for disease induction, but also disease progression. Thus, inhibition of the alternative pathway by CRIg constitutes a promising therapeutic avenue for the prevention and treatment of diseases and disorders the pathogenesis of which involves the alternative pathway of complement. For further details see, e.g. Helmy et al., *Cell*, 125(1):29-32 2006) and Katschke et al., *J. Exp Med* 204(6):1319-1325 (2007).

**[0078]** However, CRIg affinity for the convertase subunit C3b is low (micromolar range). In order to generate a more potent inhibitor to develop a therapeutic reagent, the crystal structure of CRIg in complex with C3b was used as a guide and we employed phage display technology to generate CRIg variants with improved binding affinity for C3b.

**[0079]** Thus, the present invention concerns CRIg variants with improved properties, such as improved binding affinity for C3b and enhanced inhibitory efficacy.

### Identification of affinity matured CRIg variants

**[0080]** As described in greater detail in the Example, phage display of protein or peptide libraries offers a useful methodology for the selection of CRIg variants with improved binding affinity for C3b and/or other improved properties, such as enhanced biological activity (Smith, G. P., (1991) *Curr. Opin. Biotechnol.* 2:668-673). High affinity proteins, displayed in a monovalent fashion as fusions with the M13 gene III coat protein (Clackson, T., (1994) et al., *Trends Biotechnol.* 12:173-183), can be identified by cloning and sequencing the corresponding DNA packaged in the phagemid particles after a number of rounds of binding selection.

**[0081]** Affinity maturation using phage display has been described, for example, in Lowman et al., *Biochemistry* 30(45): 10832-10838 (1991), see also Hawkins et al, *J. Mol Biol.* 254: 889-896 (1992), and in the Example below. While not

strictly limited to the following description, this process can be described briefly as: several sites within a predetermined region are mutated to generate all possible amino acid substitutions at each site. The antibody mutants thus generated are displayed in a monovalent fashion from filamentous phage particles as fusions to the gene III product of M13 packaged within each particle. The phage expressing the various mutants can be cycled through rounds of binding selection, followed by isolation and sequencing of those mutants which display high affinity. The method is also described in U.S. Pat. No. 5,750,373, issued May 12, 1998.

**[0082]** A modified procedure involving pooled affinity display is described in Cunningham, B. C. et al, EMBO J. 13(11), 2508-2515 (1994). The method provides a method for selecting novel binding polypeptides comprising: a) constructing a replicable expression vector comprising a first gene encoding a polypeptide, a second gene encoding at least a portion of a natural or wild-type phage coat protein wherein the first and second genes are heterologous, and a transcription regulatory element operably linked to the first and second genes, thereby forming a gene fusion encoding a fusion protein; b) mutating the vector at one or more selected positions within the first gene thereby forming a family of related plasmids; c) transforming suitable host cells with the plasmids; d) infecting the transformed host cells with a helper phage having a gene encoding the phage coat protein; e) culturing the transformed infected host cells under conditions suitable for forming recombinant phagemid particles containing at least a portion of the plasmid and capable of transforming the host, the conditions adjusted so that no more than a minor amount of phagemid particles display more than one copy of the fusion protein on the surface of the particle; f) contacting the phagemid particles with a target molecule so that at least a portion of the phagemid particles bind to the target molecule; and g) separating the phagemid particles that bind from those that do not. Preferably, the method further comprises transforming suitable host cells with recombinant phagemid particles that bind to the target molecule and repeating steps d) through g) one or more times.

**[0083]** It is noted that, while the CRIg variants of the present invention have been identified using phage display, other techniques and other display techniques can also be used to identify CRIg variants with improved properties, including affinity matured CRIg variants.

**[0084]** The affinity matured CRIg variants of the present invention were designed to cover the contact area between CRIg and C3b, which was identified using the crystal structure of a CRIg and C3b:CRIg complex disclosed in U.S. application publication no. 20080045697. In particular, as shown in Table 1, libraries 1-5 were designed to cover residues E8-K15, R41-T47, S54-Q64, E85-Q99, and Q105-K111, respectively, of the native sequence full-length CRIg molecule of SEQ ID NO: 2.

**[0085]** In one embodiment, the CRIg variants herein contain an amino acid substitution at one or more amino acid positions selected from the group consisting of positions 8, 14, 18, 42, 44, 45, 60, 64, 86, 99, 105, and 110 in the amino acid sequence of SEQ ID NO: 2.

**[0086]** Representative CRIg variants herein are set forth in Table 3.

**[0087]** Preferably, the substitution is at one or more of amino acid positions 60, 64, 86, 99, 105 and 110 of the amino acid sequence of full-length native CRIg of SEQ ID NO: 2.

**[0088]** Without limitation, affinity matured CRIg variants specifically include one or more of the following substitutions within the SEQ ID NO: 2: E8W, W14F, E8Y /W14F; P45F; G42D/D44H/P45F; Q60I; Q64R; Q60I/Q64R; M86Y; M86W, M86F, M86W/Q99R; M86F/Q99R; K110D, K110N; Q105R/K110N; Q105R/K110Q; Q105K/K110D.

**[0089]** Further variants of native sequence CRIg of SEQ ID NO: 2 with two or more amino acid substitutions are shown in Table 3. Specifically included within this group are Q64R/M86Y; Q60I/Q64R/E8Y; Q60I/Q64R/G42D; Q60I/Q64R/P45F; Q60I/Q64R/G42D/D44H/P45F; Q60I/Q64R/M86Y; Q60I/Q64R/Q105R; Q60I/Q64R/Q105K; Q60I/Q64R/K110N; Q60I/Q105R/K110N; M86Y/E8Y; M86Y/G42D/D44H/P45F; M86Y/P45F; M86Y/G42D/D44H/P45F; M86Y/Q99K/M86Y/Q99R/M86Y/Q105R/M86Y/Q105K/M86Y/Q105R/K110N.

**[0090]** Preferred CRIg variants herein comprise a mutation selected from the group consisting of: Q60I; Q64R; Q60I/Q64R; M86Y; Q99L; Q105K/K110D; E8W/Q105R/K110N; Q64R/M86Y; Q60I/Q64R/E8Y; Q60I/Q64R/G42D; Q60I/Q64R/P45F; Q60I/Q64R/G42D/D44H/P45F; Q60I/Q64R/M86Y; Q60I/Q64R/Q105R; Q60I/Q64R/Q105K; Q60I/Q64R/K110N; M86Y/P45F; M86Y/Q105K.

**[0091]** Particularly preferred variants comprise the mutations Q60I/Q64R/M86Y or Q60I/Q64R/G42D/D44H/P45F.

**[0092]** Variants which contain one or more of the mutations listed above or in Tables 3 and 4 but otherwise retain the native CRIg sequence of SEQ ID NO: 2 are specifically included herein. Such variants will be designated herein by listing the particular mutation followed by "CRIg." Thus for example, a variant which differs from native sequence CRIg of SEQ ID NO: 2 only by the mutation E8W will be designated as "E8W CRIg," a variant which differs from native sequence CRIg of SEQ ID NO: 2 only by the mutations Q60I/Q64R/M86Y will be designated as "Q60I/Q64R/M86Y CRIg," etc.

#### Preparation of CRIg variants

**[0093]** Various techniques are available which may be employed to produce DNA, which can encode proteins for the recombinant synthesis of the CRIg variants of the invention. For instance, it is possible to derive DNA based on naturally

occurring DNA sequences that encode for changes in an amino acid sequence of the resultant protein. These mutant DNA can be used to obtain the CRIg variants of the present invention. These techniques contemplate, in simplified form, obtaining a gene encoding a native CRIg polypeptide, modifying the genes by recombinant techniques such as those discussed below, inserting the genes into an appropriate expression vector, inserting the vector into an appropriate host cell, culturing the host cell to cause expression of the desired CRIg variant, and purifying the molecule produced thereby.

**[0094]** Somewhat more particularly, a DNA sequence encoding a CRIg variant of the present invention is obtained by synthetic construction of the DNA sequence as described in standard textbooks, such as, for example, Sambrook, J. et al., *Molecular Cloning* (2nd ed.), Cold Spring Harbor Laboratory, N.Y., (1989).

#### a. Oligonucleotide-Mediated Mutagenesis

**[0095]** Oligonucleotide-mediated mutagenesis is the preferred method for preparing substitution, deletion, and insertion variants of a native CRIg polypeptide or a fragment thereof. This technique is well known in the art as described by Zoller et al., *Nucleic Acids Res.* 10: 6487-6504 (1987). Briefly, nucleic acid encoding the starting polypeptide sequence is altered by hybridizing an oligonucleotide encoding the desired mutation to a DNA template, where the template is the single-stranded form of the plasmid containing the unaltered or native DNA sequence of encoding nucleic acid. After hybridization, a DNA polymerase is used to synthesize an entire second complementary strand of the template which will thus incorporate the oligonucleotide primer, and will code for the selected alteration of starting nucleic acid.

**[0096]** Generally, oligonucleotides of at least 25 nucleotides in length are used. An optimal oligonucleotide will have 12 to 15 nucleotides that are completely complementary to the template on either side of the nucleotide(s) coding for the mutation. This ensures that the oligonucleotide will hybridize properly to the single-stranded DNA template molecule. The oligonucleotides are readily synthesized using techniques known in the art such as that described by Crea et al., *Proc. Natl. Acad. Sci. USA* 75: 5765 (1978).

**[0097]** If phage display is used, the DNA template can only be generated by those vectors that are either derived from bacteriophage M13 vectors (the commonly available M13mp18 and M13mp19 vectors are suitable), or those vectors that contain a single-stranded phage origin or replication as described by Viera et al., *Meth. Enzymol.* 153: 3 (1987). Thus, the DNA that is to be mutated must be inserted into one of these vectors in order to generate a single-stranded template. Production of the single-stranded template is described in sections 4.21-4.41 of Sambrook et al., *supra*.

**[0098]** To alter the native DNA sequence, the oligonucleotide is hybridized to the single stranded template under suitable hybridization conditions. A DNA polymerizing enzyme, usually the Klenow fragment of DNA polymerase I, is then added to synthesize the complementary strand of the template using the oligonucleotide as a primer for synthesis. A heteroduplex molecule is thus formed such that one strand of DNA encodes the mutated form of CRIg, and the other strand (the original template) encodes the native, unaltered sequence of CRIg. This heteroduplex molecule is then transformed into a suitable host cell, usually a prokaryote such as *E. coli* JM-101. After growing the cells, they are plated onto agarose plates and screened using the oligonucleotide primer radiolabelled with <sup>32</sup>Phosphate to identify the bacterial colonies that contain the mutated DNA.

**[0099]** The method described immediately above may be modified such that a homoduplex molecule is created wherein both strands of the plasmid contain the mutation(s). The modifications are as follows: The single-stranded oligonucleotide is annealed to the single-stranded template as described above. A mixture of three deoxyribonucleotides, deoxyriboadenosine (dATP), deoxyriboguanosine (dGTP), and deoxyribothymidine (dTTP), is combined with a modified thio-deoxyribocytosine called dCTP-(aS) (Amersham). This mixture is added to the template-oligonucleotide complex. Upon addition of DNA polymerase to this mixture, a strand of DNA identical to the template except for the mutated bases is generated. In addition, this new strand of DNA will contain dCTP-(aS) instead of dCTP, which serves to protect it from restriction endonuclease digestion. After the template strand of the double-stranded heteroduplex is nicked with an appropriate restriction enzyme, the template strand can be digested with ExoIII nuclease or another appropriate nuclease past the region that contains the site(s) to be mutagenized. The reaction is then stopped to leave a molecule that is only partially single-stranded. A complete double-stranded DNA homoduplex is then formed using DNA polymerase in the presence of all four deoxyribonucleotide triphosphates, ATP, and DNA ligase. This homoduplex molecule can then be transformed into a suitable host cell such as *E. coli* JM101, as described above.

**[0100]** Mutants with more than one amino acid to be substituted may be generated in one of several ways. If the amino acids are located close together in the polypeptide chain, they may be mutated simultaneously using one oligonucleotide that codes for all of the desired amino acid substitutions. If, however, the amino acids are located some distance from each other (separated by more than about ten amino acids), it is more difficult to generate a single oligonucleotide that encodes all of the desired changes. Instead, one or two alternative methods may be employed.

**[0101]** In the first method, a separate oligonucleotide is generated for each amino acid to be substituted. The oligonucleotides are then annealed to the single-stranded template DNA simultaneously, and the second strand of DNA that is synthesized from the template will encode all of the desired amino acid substitutions. The alternative method involves two or more rounds of mutagenesis to produce the desired mutant. The first round is as described for the single mutants:

wild-type DNA is used for the template, and oligonucleotide encoding the first desired amino acid substitution(s) is annealed to this template, and the heteroduplex DNA molecule is then generated. The second round of mutagenesis utilizes the mutated DNA produced in the first round of mutagenesis as the template. Thus, this template already contains one or more mutations. The oligonucleotide encoding the additional desired amino acid substitution(s) is then annealed to this template, and the resulting strand of DNA now encodes mutations from both the first and second rounds of mutagenesis. This resultant DNA can be used as a template in a third round of mutagenesis, and so on.

#### b. Cassette Mutagenesis

**[0102]** This method is also a preferred method for preparing substitution, deletion, and insertion variants of CRIg. The method is based on that described by Wells et al. Gene 34: 315 (1985). The starting material is the plasmid (or other vector) comprising gene 1, the gene to be mutated. The codon(s) to be mutated in the nucleic acid encoding the starting CRIg molecule are identified. There must be a unique restriction endonuclease site on each side of the identified mutation site(s). If no such restriction sites exist, they may be generated using the above-described oligonucleotide-mediated mutagenesis method to introduce them at appropriate locations in gene 1. After the restriction sites have been introduced into the plasmid, the plasmid is cut at these sites to linearize it. A double-stranded oligonucleotide encoding the sequence of the DNA between the restriction sites but containing the desired mutation(s) is synthesized using standard procedures. The two strands are synthesized separately and then hybridized together using standard techniques. This double-stranded oligonucleotide is referred to as the cassette. This cassette is designed to have 3' and 5' ends that are compatible with the ends of the linearized plasmid, such that it can be directly ligated to the plasmid. This plasmid now contains the mutated DNA sequence of CRIg.

#### c. Recombinant production of CRIg variants

**[0103]** The DNA encoding variants are then inserted into an appropriate plasmid or vector. The vector is used to transform a host cell. In general, plasmid vectors containing replication and control sequences which are derived from species compatible with the host cell are used in connection with those hosts. The vector ordinarily carries a replication site, as well as sequences which encode proteins that are capable of providing phenotypic selection in transformed cells.

**[0104]** For example, *E. coli* may be transformed using pBR322, a plasmid derived from an *E. coli* species (Mandel, M. et al., (1970) J. Mol. Biol. 53:154). Plasmid pBR322 contains genes for ampicillin and tetracycline resistance, and thus provides easy means for selection. Other vectors include different features such as different promoters, which are often important in expression. For example, plasmids pKK223-3, pDR720, and pPL- $\lambda$  represent expression vectors with the *tac*, *trp*, or *P<sub>L</sub>* promoters that are currently available (Pharmacia Biotechnology).

**[0105]** Other preferred vectors can be constructed using standard techniques by combining the relevant traits of the vectors described herein. Relevant traits of the vector include the promoter, the ribosome binding site, the variant gene or gene fusion, the signal sequence, the antibiotic resistance markers, the copy number, and the appropriate origins of replication.

**[0106]** Suitable host cells for cloning or expressing the DNA in the vectors herein include prokaryote, yeast, or higher eukaryote cells. Suitable prokaryotes for this purpose include eubacteria, such as Gram-negative or Gram-positive organisms, for example, Enterobacteriaceae such as *Escherichia*, e.g., *E. coli*, *Enterobacter*, *Erwinia*, *Klebsiella*, *Proteus*, *Salmonella*, e.g., *Salmonella typhimurium*, *Serratia*, e.g., *Serratia marcescens*, and *Shigella*, as well as Bacilli such as *B. subtilis* and *B. licheniformis* (e.g., *B. licheniformis* 41P disclosed in DD 266,710 published Apr. 12, 1989), *Pseudomonas* such as *P. aeruginosa*, and *Streptomyces*. One preferred *E. coli* cloning host is *E. coli* 294 (ATCC 31,446), although other strains such as *E. coli* B, *E. coli* X 1776 (ATCC 31,537), and *E. coli* W3110 (ATCC 27,325) are suitable. These examples are illustrative rather than limiting.

**[0107]** In addition to prokaryotes, eukaryotic microbes such as filamentous fungi or yeast are suitable cloning or expression hosts for antibody-encoding vectors. *Saccharomyces cerevisiae*, or common baker's yeast, is the most commonly used among lower eukaryotic host microorganisms. However, a number of other genera, species, and strains are commonly available and useful herein, such as *Schizosaccharomyces pombe*; *Kluyveromyces* hosts such as, e.g., *K. lactis*, *K. fragilis* (ATCC 12,424), *K. bulgaricus* (ATCC 16,045), *K. wickerhamii* (ATCC 24,178), *K. waltii* (ATCC 56,500), *K. drosophilum* (ATCC 36,906), *K. thermotolerans*, and *K. marxianus*; *Yarrowia* (EP 402,226); *Pichia pastoris* (EP 183,070); *Candida*; *Trichoderma reesia* (EP 244,234); *Neurospora crassa*; *Schwanniomyces* such as *Schwanniomyces occidentalis*; and filamentous fungi such as, e.g., *Neurospora*, *Penicillium*, *Tolypocladium*, and *Aspergillus* hosts such as *A. nidulans* and *A. niger*.

**[0108]** Suitable host cells for the expression of glycosylated antibody are derived from multicellular organisms. Examples of invertebrate cells include plant and insect cells. Numerous baculoviral strains and variants and corresponding permissive insect host cells from hosts such as *Spodoptera frugiperda* (caterpillar), *Aedes aegypti* (mosquito), *Aedes albopictus* (mosquito), *Drosophila melanogaster* (fruitfly), and *Bombyx mori* have been identified. A variety of viral strains

for transfection are publicly available, e.g., the L-1 variant of *Autographa californica* NPV and the Bm-5 strain of *Bombyx mori* NPV, and such viruses may be used in the present invention, particularly for transfection of *Spodoptera frugiperda* cells. Plant cell cultures of cotton, corn, potato, soybean, petunia, tomato, and tobacco can also be utilized as hosts.

**[0109]** However, interest has been greatest in vertebrate cells, and propagation of vertebrate cells in culture (tissue culture) has become a routine procedure. Examples of useful mammalian host cell lines are monkey kidney CV1 line transformed by SV40 (COS-7, ATCC CRL 1651); human embryonic kidney line (293 or 293 cells subcloned for growth in suspension culture, Graham et al., J. Gen. Virol. 36:59 (1977)); baby hamster kidney cells (BHK, ATCC CCL 10); Chinese hamster ovary cells/-DHFR (CHO, Urlaub et al., Proc. Natl. Acad. Sci. USA 77:4216 (1980)); mouse sertoli cells (TM4, Mather, Biol. Reprod. 23:243-251 (1980)); monkey kidney cells (CV1 ATCC CCL 70); African green monkey kidney cells (VERO-76, ATCC CRL-1587); human cervical carcinoma cells (HELA, ATCC CCL 2); canine kidney cells (MDCK, ATCC CCL 34); buffalo rat liver cells (BRL 3A, ATCC CRL 1442); human lung cells (W138, ATCC CCL 75); human liver cells (Hep G2, HB 8065); mouse mammary tumor (MMT 060562, ATCC CCL51); TRI cells (Mather et al., Annals N.Y. Acad. Sci. 383:44-68 (1982)); MRC 5 cells; FS4 cells; and a human hepatoma line (Hep G2).

**[0110]** Host cells are transformed with the above-described expression or cloning vectors for the production of the CRlg variants herein and cultured in conventional nutrient media modified as appropriate for inducing promoters, selecting transformants, or amplifying the genes encoding the desired sequences.

**[0111]** The host cells used to produce the CRlg variants of this invention may be cultured in a variety of media. Commercially available media such as Ham's F10 (Sigma), Minimal Essential Medium ((MEM), (Sigma), RPMI-1640 (Sigma), and Dulbecco's Modified Eagle's Medium ((DMEM), (Sigma) are suitable for culturing the host cells. In addition, any of the media described in Ham et al., Meth. Enz. 58:44 (1979), Barnes et al., Anal. Biochem. 102:255 (1980), U.S. Pat. Nos. 4,767,704; 4,657,866; 4,927,762; 4,560,655; or 5,122,469; WO 90/03430; WO 87/00195; or U.S. Pat. No. Re. 30,985 may be used as culture media for the host cells. Any of these media may be supplemented as necessary with hormones and/or other growth factors (such as insulin, transferrin, or epidermal growth factor), salts (such as sodium chloride, calcium, magnesium, and phosphate), buffers (such as HEPES), nucleotides (such as adenosine and thymidine), antibiotics (such as GENTAMYCIN™), trace elements (defined as inorganic compounds usually present at final concentrations in the micromolar range), and glucose or an equivalent energy source. Any other necessary supplements may also be included at appropriate concentrations that would be known to those skilled in the art. The culture conditions, such as temperature, pH, and the like, are those previously used with the host cell selected for expression, and will be apparent to the ordinarily skilled artisan.

**[0112]** When using recombinant techniques, the CRlg variant can be produced intracellularly, in the periplasmic space, or directly secreted into the medium. If the CRlg variant is produced intracellularly, as a first step, the particulate debris, either host cells or lysed cells, is removed, for example, by centrifugation or ultrafiltration. Where the CRlg variant is secreted into the medium, supernatants from such expression systems are generally first concentrated using a commercially available protein concentration filter, for example, an Amicon or Millipore Pellicon ultrafiltration unit. A protease inhibitor such as PMSF may be included in any of the foregoing steps to inhibit proteolysis and antibiotics may be included to prevent the growth of adventitious contaminants.

**[0113]** The CRlg variant prepared from the cells can be purified by known techniques, using, for example, hydroxylapatite chromatography, gel electrophoresis, dialysis, and/or affinity chromatography.

#### Further modifications of CRlg variants

**[0114]** The CRlg variants of the present invention may also be modified in a way to form a chimeric molecule comprising CRlg variant, including fragments thereof, fused to another, heterologous polypeptide or amino acid sequence. In one embodiment, such a chimeric molecule comprises a fusion of CRlg variant, or a fragment thereof, with a tag polypeptide which provides an epitope to which an anti-tag antibody can selectively bind. The epitope tag is generally placed at the amino- or carboxyl-terminus of the variant CRlg polypeptide. The presence of such epitope-tagged forms of the CRlg variant can be detected using an antibody against the tag polypeptide. Also, provision of the epitope tag enables the CRlg polypeptide to be readily purified by affinity purification using an anti-tag antibody or another type of affinity matrix that binds to the epitope tag. Various tag polypeptides and their respective antibodies are well known in the art. Examples include poly-histidine (poly-his) or poly-histidine-glycine (poly-his-gly) tags; the flu HA tag polypeptide and its antibody 12CA5 [Field et al., Mol. Cell. Biol., 8:2159-2165 (1988)]; the c-myc tag and the 8F9, 3C7, 6E10, G4, B7 and 9E10 antibodies thereto (Evan et al., Molecular and Cellular Biology, 5:3610-3616 (1985)); and the Herpes Simplex virus glycoprotein D (gD) tag and its antibody (Paborsky et al., Protein Engineering, 3(6):547-553 (1990)). Other tag polypeptides include the Flag-peptide (Hopp et al., BioTechnology, 6:1204-1210 (1988)); the KT3 epitope peptide (Martin et al., Science, 255:192-194 (1992)); an .quadrature.-tubulin epitope peptide [Skinner et al., J. Biol. Chem., 266:15163-15166 (1991)]; and the T7 gene 10 protein peptide tag (Lutz-Freyermuth et al., Proc. Natl. Acad. Sci. USA, 87:6393-6397 (1990)).

**[0115]** In another embodiment, the chimeric molecule may comprise a fusion of the CRlg variant or a fragment thereof with an immunoglobulin or a particular region of an immunoglobulin. For a bivalent form of the chimeric molecule, such



a fusion could be to the Fc region of an IgG molecule. These fusion polypeptides are antibody-like molecules which combine the binding specificity of a heterologous protein (an "adhesin") with the effector functions of immunoglobulin constant domains, and are often referred to as immunoadhesins. Structurally, the immunoadhesins comprise a fusion of an amino acid sequence with the desired binding specificity which is other than the antigen recognition and binding site of an antibody (i.e., is "heterologous"), and an immunoglobulin constant domain sequence. The adhesin part of an immunoadhesin molecule typically is a contiguous amino acid sequence comprising at least the binding site of a receptor or a ligand. The immunoglobulin constant domain sequence in the immunoadhesin may be obtained from any immunoglobulin, such as IgG-1, IgG-2, IgG-3, or IgG-4 subtypes, IgA (including IgA-1 and IgA-2), IgE, IgD or IgM.

**[0116]** The simplest and most straightforward immunoadhesin design combines the binding region(s) of the "adhesin" protein with the hinge and Fc regions of an immunoglobulin heavy chain. Ordinarily, when preparing the CRlg-immunoglobulin chimeras of the present invention, nucleic acid encoding the extracellular domain of CRlg will be fused C-terminally to nucleic acid encoding the N-terminus of an immunoglobulin constant domain sequence, however N-terminal fusions are also possible.

**[0117]** Typically, in such fusions the encoded chimeric polypeptide will retain at least functionally active hinge and CH2 and CH3 domains of the constant region of an immunoglobulin heavy chain. Fusions are also made to the C-terminus of the Fc portion of a constant domain, or immediately N-terminal to the CH1 of the heavy chain or the corresponding region of the light chain.

**[0118]** The precise site at which the fusion is made is not critical; particular sites are well known and may be selected in order to optimize the biological activity, secretion or binding characteristics of the CRlg-immunoglobulin chimeras.

**[0119]** In some embodiments, the CRlg-immunoglobulin chimeras are assembled as monomers, or hetero- or homo-multimer, and particularly as dimers or tetramers, essentially as illustrated in WO 91/08298.

**[0120]** In a preferred embodiment, the CRlg extracellular domain sequence is fused to the N-terminus of the C-terminal portion of an antibody (in particular the Fc domain), containing the effector functions of an immunoglobulin, e.g. immunoglobulin G.sub.1 (IgG 1). It is possible to fuse the entire heavy chain constant region to the CRlg extracellular domain sequence. However, more preferably, a sequence beginning in the hinge region just upstream of the papain cleavage site (which defines IgG Fc chemically; residue 216, taking the first residue of heavy chain constant region to be 114, or analogous sites of other immunoglobulins) is used in the fusion. In a particularly preferred embodiment, the CRlg amino acid sequence is fused to the hinge region and CH2 and CH3, or to the CH1, hinge, CH2 and CH3 domains of an IgG1, gG2, or IgG3 heavy chain. The precise site at which the fusion is made is not critical, and the optimal site can be determined by routine experimentation.

**[0121]** In some embodiments, the CRlg-immunoglobulin chimeras are assembled as multimer, and particularly as homo-dimers or -tetramers. Generally, these assembled immunoglobulins will have known unit structures. A basic four chain structural unit is the form in which IgG, IgD, and IgE exist. A four unit is repeated in the higher molecular weight immunoglobulins; IgM generally exists as a pentamer of basic four units held together by disulfide bonds. IgA globulin, and occasionally IgG globulin, may also exist in multimeric form in serum. In the case of multimer, each four unit may be the same or different.

**[0122]** Alternatively, the CRlg extracellular domain sequence can be inserted between immunoglobulin heavy chain and light chain sequences such that an immunoglobulin comprising a chimeric heavy chain is obtained. In this embodiment, the CRlg sequence is fused to the 3' end of an immunoglobulin heavy chain in each arm of an immunoglobulin, either between the hinge and the CH2 domain, or between the CH2 and CH3 domains. Similar constructs have been reported by Hoogenboom et al., Mol. Immunol., 28:1027-1037 (1991).

**[0123]** Although the presence of an immunoglobulin light chain is not required in the immunoadhesins of the present invention, an immunoglobulin light chain might be present either covalently associated to a CRlg-immunoglobulin heavy chain fusion polypeptide, or directly fused to the CRlg extracellular domain. In the former case, DNA encoding an immunoglobulin light chain is typically coexpressed with the DNA encoding the CRlg-immunoglobulin heavy chain fusion protein. Upon secretion, the hybrid heavy chain and the light chain will be covalently associated to provide an immunoglobulin-like structure comprising two disulfide-linked immunoglobulin heavy chain-light chain pairs. Methods suitable for the preparation of such structures are, for example, disclosed in U.S. Pat. No. 4,816,567 issued Mar. 28, 1989.

#### Pharmaceutical compositions

**[0124]** The CRlg variants of the present invention can be administered for the treatment of diseases the pathology of which involves the alternative complement pathway.

**[0125]** Therapeutic formulations are prepared for storage by mixing the active molecule having the desired degree of purity with optional pharmaceutically acceptable carriers, excipients or stabilizers (Remington's Pharmaceutical Sciences 16th edition, Osol, A. Ed. [1980]), in the form of lyophilized formulations or aqueous solutions. Acceptable carriers, excipients, or stabilizers are nontoxic to recipients at the dosages and concentrations employed, and include buffers such as phosphate, citrate, and other organic acids; antioxidants including ascorbic acid and methionine; preservatives

(such as octadecyldimethylbenzyl ammonium chloride; hexamethonium chloride; benzalkonium chloride, benzethonium chloride; phenol, butyl or benzyl alcohol; alkyl parabens such as methyl or propyl paraben; catechol; resorcinol; cyclohexanol; 3-pentanol; and m-cresol); low molecular weight (less than about 10 residues) polypeptides; proteins, such as serum albumin, gelatin, or immunoglobulins; hydrophilic polymers such as polyvinylpyrrolidone; amino acids such as glycine, glutamine, asparagine, histidine, arginine, or lysine; monosaccharides, disaccharides, and other carbohydrates including glucose, mannose, or dextrans; chelating agents such as EDTA; sugars such as sucrose, mannitol, trehalose or sorbitol; salt-forming counter-ions such as sodium; metal complexes (e.g. Zn-protein complexes); and/or non-ionic surfactants such as TWEEN™, PLURONICS™ or polyethylene glycol (PEG).

**[0126]** Lipofections or liposomes can also be used to deliver the polypeptide, antibody, or an antibody fragment, into cells. Where antibody fragments are used, the smallest fragment which specifically binds to the binding domain of the target protein is preferred. For example, based upon the variable region sequences of an antibody, peptide molecules can be designed which retain the ability to bind the target protein sequence. Such peptides can be synthesized chemically and/or produced by recombinant DNA technology (see, e.g. Marasco et al., Proc. Natl. Acad. Sci. USA 90, 7889-7893 [1993]).

**[0127]** The formulation herein may also contain more than one active compound as necessary for the particular indication being treated, preferably those with complementary activities that do not adversely affect each other. Such molecules are suitably present in combination in amounts that are effective for the purpose intended.

**[0128]** The active molecules may also be entrapped in microcapsules prepared, for example, by coacervation techniques or by interfacial polymerization, for example, hydroxymethylcellulose or gelatin-microcapsules and poly-(methylmethacrylate) microcapsules, respectively, in colloidal drug delivery systems (for example, liposomes, albumin microspheres, microemulsions, nano-particles and nanocapsules) or in macroemulsions. Such techniques are disclosed in Remington's Pharmaceutical Sciences 16th edition, Osol, A. Ed. (1980).

**[0129]** The formulations to be used for in vivo administration must be sterile. This is readily accomplished by filtration through sterile filtration membranes.

**[0130]** Sustained-release preparations may be prepared. Suitable examples of sustained-release preparations include semipermeable matrices of solid hydrophobic polymers containing the antibody, which matrices are in the form of shaped articles, e.g. films, or microcapsules. Examples of sustained-release matrices include polyesters, hydrogels (for example, poly(2-hydroxyethyl-methacrylate), or poly(vinylalcohol)), polylactides (U.S. Pat. No. 3,773,919), copolymers of L-glutamic acid and .gamma. ethyl-L-glutamate, nondegradable ethylene-vinyl acetate, degradable lactic acid-glycolic acid copolymers such as the LUPRON DEPOT™ (injectable microspheres composed of lactic acid-glycolic acid copolymer and leuprolide acetate), and poly-D-(-)-3-hydroxybutyric acid. While polymers such as ethylene-vinyl acetate and lactic acid-glycolic acid enable release of molecules for over 100 days, certain hydrogels release proteins for shorter time periods. When encapsulated antibodies remain in the body for a long time, they may denature or aggregate as a result of exposure to moisture at 37 C, resulting in a loss of biological activity and possible changes in immunogenicity. Rational strategies can be devised for stabilization depending on the mechanism involved. For example, if the aggregation mechanism is discovered to be intermolecular S-S bond formation through thio-disulfide interchange, stabilization may be achieved by modifying sulfhydryl residues, lyophilizing from acidic solutions, controlling moisture content, using appropriate additives, and developing specific polymer matrix compositions.

#### Methods of treatment

**[0131]** As a result of their ability to inhibit complement activation, in particular the alternative complement pathway, the CRIg variants of the present invention find utility in the prevention and/or treatment of complement-associated diseases and pathological conditions. Such diseases and conditions include, without limitation, complement-associated, inflammatory and autoimmune diseases.

**[0132]** Specific examples of complement-associated, inflammatory and immune related diseases and disorders that can be targeted by the CRIg variants herein have been listed earlier.

**[0133]** Further details of the invention are illustrated by the following non-limiting Examples.

#### Example 1

##### Preparation of affinity matured CRIg variants

##### Materials And Methods

##### Materials:

**[0134]** *Materials-Enzymes* and M13-KO7 helper phage (New England Biolabs); Maxisorp immunoplates plates (Nunc.

Roskilde, Denmark); 96-well U-bottom Polypropylene plate (COSTAR; Cat. #3365); 96-well flat bottom, non-binding plate (NUNC; Cat. #269620); Horseradish peroxidase/anti-M13 antibody conjugate (Pharmacia); 3,3', 5,5'-Tetramethylbenzidine, H<sub>2</sub>O<sub>2</sub> peroxidase substrate (TEB) (Kirkegaard and Perry Laboratories, Inc); *Escherichia coli* XL1-blue and *E. coli* BL21(DE3) (Stratagene); Bovine serum albumin (BSA) and Tween 20 (Sigma); Ni-NTA agarose (Qiagen); Rabbit RBC (Colorado Serum Company; Cat. #CS1081); Gelatin Veronal Buffer (GVB) [100mL Veronal Buffer (BioWhittaker; Cat. #12-624E); Gelatin (Bovine Skin Type B; SIGMA; Cat. #G9391-100G); C1q-depleted Serum (CompTech; Cat. #A300); fH Protein (Complement Technology; Cat. #A137); Anti-FLAG-HRP, mAb in 50% glycerol, Sigma Cat#A-8592 1.1mg/mL

#### Construction of phage-display CRIg libraries

**[0135]** A DNA fragment encoding CRIg was ligated into a XhoI and SpeI -digested phagemid vector (p3DvlzPDZ-gD) (Kunkel et al., Methods Enzymol. 154:367-382 (1987)) as wild type control and template for design CRIg variants. Then, templates with the TAA stop codon at each residue targeted for randomization were prepared from CJ239 *E. coli* cells (Kunkel et al., 1987, supra). A soft randomization strategy was used for CRIg variants selection, in which a mutation rate of approximately 50% was introduced at selected position by using a poisoned oligonucleotide strategy with 70-10-10-10 mixtures of bases favoring the wild-type nucleotides. In the libraries design: 5=50% A, 10% G, 10% C and 10% T; 6=50% G, 10% A, 10% C and 10% T; 7=50% C, 10% A, 10% G and 10% T; 8=50% T, 10% A, 10% G and 10% C.

**[0136]** Five libraries have been designed.

BCR1, ATC CTG GAA GTG CAA 656 (SEQ ID NO: 7) AGT GTA ACA GGA CCT 866 (SEQ ID NO: 8) 555 GGG GAT GTG AAT CTT (SEQ ID NO: 9) in library 1;  
BCR2, AAG TGG CTG GTA CAA 768 (SEQ ID NO: 10) 668 TCA 657 775 688 577 ATC TTT (SEQ ID NO: 11) 786 CGT 657 TCT TCT GGA GAC CAT (SEQ ID NO: 12) in library 2;  
BCR3, TTT CTA CGT GAC TCT (SEQ ID NO: 13) 877 668 657 757 588 756 756 678 555 TAC 756 GGC CGC CTG CAT GTVG (SEQ ID NO: 14) in library 3;  
BCR4, CAA TTG AGC ACC CTG (SEQ ID NO: 15) 656 586 657 GAC 768 AGC CAC TAC ACG TGT 656 (SEQ ID NO: 16) GTC ACC TGG 756 (SEQ ID NO: 17) ACT CCT GAT GGC AAC (SEQ ID NO: 18) in library 4;  
BCR5, ACT CCT GAT GGC AAC 756 (SEQ ID NO: 19) GTC 688 768 657 555 ATT ACT GAG CTC CGT (SEQ ID NO: 20) in library 5.

**[0137]** Side-directed mutagenesis for the point mutations was carried out as above by using appropriated codons to produce the respective mutations, and the correct clones were confirmed by sequence.

#### Library sorting and screening to select CRIg variants:

**[0138]** Maxisorp immunoplates were coated overnight at 4 °C with C3b (5 µg/ml) and blocked for 1 hr at room temperature with phosphate-buffered saline (PBS) and 0.05% (w/v) bovine serum albumin (BSA). Phage libraries were added to the C3b coated plates and incubated at room temperature for 3 hr. The plates were washed ten times and bound phage were eluted with 50mM HCl and neutralized with equal volume of 1.0 M Tris base (pH7.5). Recovered phages were amplified by passage through *E. coli* XL 1-blue and were used for additional rounds of binding selections. After 5 rounds, we select 12 individual clones from each library and grow them in a 96-well format in 500 µl of 2YT broth supplemented with carbenicillin and M13-KO7 helper phage. Two-fold serial diluted culture supernatants were added directly in 384 well plates by coated with C3b, anti-gD, BSA and unrelated protein as designed positions. Binding affinity was measured to estimate a phage concentration giving C3b significant higher than anti-gD but not to BSA and unrelated protein. We fixed the phage concentration, screening about 200 clones from each library in the same format and selected 24-48 clones in which showed significantly to bind to C3b over anti-gD from each library, then sequence them for analysis.

#### Competitive Phage ELISA

**[0139]** For estimating the binding affinity, a modified phage ELISA was used. The 96 well microtiter plates were coat with 2ug/ml 3Cb in 50mM carbonate buffer (pH9.6) at 4C overnight. The plates were then block with PBS, 0.5% BSA for 1 hour at room temperature. Phage displaying CRIg variants serially diluted in PBT buffer and binding was measured to estimate a phage concentration giving 50% of the signal at saturation. Subsaturating concentration of phage was fixed and pre-incubated for 2 h with serial dilutions of C3b, then transferred the mixture to assay plates coated with C3b. After incubating 15 min, the plates were washed with PBS, 0.05% Tween 20 and incubated 30 min with horseradish peroxidase/anti-M 13 antibody conjugate (1:5000 dilution in PBT buffer). The plates were washed, developed with TMB substrate, quenched with 1.0 M H<sub>3</sub>PO<sub>4</sub>, and read spectrophotometrically at 450 nm. The affinity (Ic50) was calculated

as the concentration of competing C3b that resulted in half-maximal phagemid binding.

#### *Protein purification*

**[0140]** A single colony of *E. coli* BL21(DE3) harboring the expression plasmid was inoculated into 30mL of LB medium supplemented with 50 µg/mL carbenicillin (LB/carb medium) and was grown overnight at 37°C. The bacteria were harvested, washed, resuspended, and inoculated into 500 mL of LB/carb medium. The culture was grown at 37°C to mid-log phase ( $A_{600} = 0.8$ ). Protein expression was induced with 0.4 mM isopropyl 1-thio-D-galactopyranoside, and the culture was grown for 24 h at 30°C. The bacteria were pelleted by centrifugation at 4000g for 15 min, washed twice with phosphate-buffered saline (PBS), and frozen for 8 h at -80°C. The pellet was resuspended in 50 mL of PBS, and the bacteria were lysed by passing through the Microfluidizer Processing or sonicate equipments. The CRIg variant proteins were purified with 2mL NI-NTA agarose and gel filtration.

#### *mutCRIg-huFc Fluid Phase Competitive Binding ELISA:*

**[0141]** huCRIg(L)-LFH was diluted to 2µg/mL in PBS, pH 7.4, and coated onto Maxisorp 384-well flat bottom plates (Nunc, Neptune, NJ) by incubating overnight (16-18hr) at 4°C (25µl/well). The plates were washed 3 times in Wash Buffer (PBS, pH7.4, 0.05% Tween 20), and 50µl/well of Block Buffer (PBS, pH 7.4, 0.5% BSA) was added to each well. The plates were allowed to block for 1-3hr; this and all subsequent incubations were performed on an orbital shaker at room temperature. During the blocking step, C3b (purified at Genentech) was diluted to 20nM in Assay Buffer (PBS pH7.4, 0.5% BSA, 0.05% Tween-20), and the mutCRIg-huFc molecules were serially diluted in Assay Buffer, over a concentration range of 20,000 - 0.34 nM. The C3b and mutCRIg-huFc molecules were then mixed 1:1 and allowed to pre-incubate for 0.5-1hr. The blocked plates were washed three times (as described above), and the C3b:mutCRIg-huFc complexes were added to the reaction plates (25µl/well). After 2hr incubation, the ELISA plates were washed three times, (as described above) and plate-bound C3b was detected by the addition of an anti-human C3b antibody (clone 5F202, US Biological, Swampscott, MA; 600ng/mL, 25µl/well). The plates were incubated for 1-2hr and washed as described above. HRP-conjugated anti-murine Fc IgG (Jackson ImmunoResearch, West Grove, PA) diluted 1:2,000 was then added (25µl/well), and the plates were incubated for 1-2hr. After a final wash, 25µl/well of TMB substrate (Kirkegaard & Perry Laboratories, Gaithersburg, MD) was added to the ELISA plates. Color development was stopped after approximately 8min by adding 25µl/well 1.0M phosphoric acid. Absorbance at 450nm and 650nm was determined using a SpectraMax 250 microtiter plate reader (Molecular Devices, Sunnyvale, CA).

#### *Complement Activation Assay:*

**[0142]** The ability of mutCRIg-Fc to inhibit complement activation was evaluated using the Wieslab™ Complement System Alternative Pathway Kit (Alpco Diagnostics, Salem, NH). Serially diluted mutCRIg-Fc (400 to 0.2 nM) and C1q deficient human serum (5%) (Complement Technology, Tyler, TX) were prepared at twice the final desired concentration, mixed 1:1, and pre-incubated for 5min on an orbital shaker at 300RPM prior to adding to the LPS-coated ELISA plates (100µl/well). The remainder of the assay was following manufacturer's instructions. Briefly, the samples in the ELISA plates were incubated for 60-70min at 37°C and then washed three times in Wash Buffer (PBS, pH7.4, 0.05% Tween 20). 100µl/well of the anti-C5b-9 conjugate was added to the ELISA plate. After a 30min incubation at room temperature, the ELISA plate was washed as described above, and 100µl of substrate was added per well, and the plates were incubated at room temperature for an additional 30min. The color development was stopped by adding 50µl/well of 5mM EDTA. Absorbance at 405nm was determined using a MultiSkan Ascent microtiter plate reader (Thermo Fisher Scientific, Milford, MA).

#### *Hemolysis inhibition assay:*

**[0143]** Rabbit red blood cells (Colorado Serum Company, Denver, CO) were washed three times with Veronal Buffer (Sigma, St. Louis, MO) containing 0.1% bovine skin gelatin (Sigma) (GVB), centrifuging at 1500rpm, 4°C for 10 minutes for each wash. After the final centrifugation step, the cells were resuspended in GVB at a final concentration of  $2 \times 10^9$  cells/mL. Complement inhibitors serially diluted in GVB were added to 96-well U-bottom polypropylene plate(s) (Costar, Cambridge, MA) at 50µL/well followed by 20µL/well of rabbit red blood cells diluted 1:2 in 0.1M MgCl<sub>2</sub>/0.1M EGTA/GVB. The in-plate complement cascade was triggered by the addition of 30µL/well C1q-depleted serum (Complement Technology, Tyler, TX), pre-diluted 1:3 with GVB. The plate(s) were incubated with gentle agitation for 30 minutes at room temperature before stopping the reaction with 100µL/well 10mM EDTA/GVB. After centrifuging the plate(s) at 1500rpm for 5 minutes, the supernatants were transferred to clear flat bottom, non-binding, 96-well plate(s) (Nunc, Neptune, NJ) and the optical densities were read at 412nm using a microplate reader (Molecular Devices, Sunnyvale, CA).

*Alpha Screen Competitive assay:*

**[0144]** The potential cross-reactivity of the mutant CRIg molecules to C3 was evaluated using the AlphaScreen® Histidine (Nickel Chelate) Detection Kit (PerkinElmer, Waltham, MA). Serially diluted human C3 and C3b (3,000 to 0.7 nM), as well as fixed concentrations of biotinylated iC3b (30 nM), and both mutant CRIg (mutCRIg) and wild-type CRIg molecules (15-60 nM) were prepared at three times the final desired concentration, mixed 1:1:1, and pre-incubated at ambient temperature for 30 minutes on an orbital shaker at 3000 TPM. A 1:1 mixture of streptavidin donor beads and nickel chelate acceptor beads (0.1 mg/mL each) was prepared at four times the final desired concentration and added to the reaction. The reaction plate was incubated at ambient temperature for 60 minutes on an orbital shaker at 3000 rpm protected from light. The plate was analyzed on an AlphaQuest®-HTS microplate analyzer (PerkinElmer, Waltham, MA).

*Surface Plasmon Resonance*

**[0145]** Affinities of C3b for mutant and wild-type CRIg were determined by using surface plasmon resonance measurements on a Biacore® A100 instrument (GE healthcare). An anti-Fc capture format was employed and the  $K_D$  was calculated from equilibrium binding measurements. The sensor chip was prepared using the anti-muFc capture kit (BR-1008-38) following instructions supplied by the manufacturer. Mutant or wild-type CRIg was diluted in running buffer (10 mM HEPES pH 7.4, 150 mM NaCl, 0.01% Tween-20) to 1 µg/mL and injections of 60 µL were made such that ~100 RU of fusion protein were captured on one spot of the chip surface. Sensorgrams were recorded for 10 min injections of solutions of varied C3b concentration over the CRIg spot with subtraction of signal for a reference spot containing the capture antibody but no CRIg. Data were obtained for a 2-fold dilution series of C3b ranging in concentration from 4 µM to 15.6 nM with the flow rate at 10 µL/min and at a temperature of 25 °C. The surface was regenerated between binding cycles by a 30 second injection of 10 mM Gly-HCl pH 1.7. Plateau values obtained at the end of each C3b injection were used to calculate  $K_D$  using the Affinity algorithm of the Biacore A100 Evaluation Software v1.1 (Safsten et al. (2006) Anal. Biochem. 353:181).

Results*Phage library design*

**[0146]** We used the crystal structure of CRIg in complex with C3b to design target libraries. Five libraries were designed to cover the contact area between CRIg and C3b (Figure 4). CRIg libraries were constructed as a fusion to the g3p minor coat protein in a monovalent phage display vector (Zhang et al., J Biol Chem 281(31): 22299-311 (2006)). We introduced stop codons by mutagenesis into the CRIg-coding portion of the phage plasmid at each residue to be randomized. Each construct containing a stop-codon was then used to generate the phage-display library (see material and method). A "soft randomization" strategy was used to select binders to maintain a wild-type sequence bias such that the selected positions were mutated only 50% of the time. All five libraries were obtained with an average diversity of  $> 10^{10}$  independent sequences per library. (Table 1).

*Selections with CRIg phage library*

**[0147]** Following four rounds of binding selection, we obtained 38 unique clones from these five libraries. (Table 2). In library 1, lysine at position 15 was conserved. Aromatic residues, tyrosine and tryptophan, replaced glutamic acid at position 8. Position 14 was occupied by either the parental tryptophan or a homologous phenylalanine. In library 2, we sequenced 24 clones and all of them revealed consensus. Position 42, 46 and 47 were conserved as wild type. Asparagin, histidine and phenylalanine replaced the wild type sequence at position 43, 44 and 45. In library 3, we randomized 10 positions and the sequences exhibited complete conservation at position 54, 55, 56, 57, 58, 61, 62 and 63. Isoleucine or lysine was occupied at position 60. At position 64, glutamine was replaced by arginine or conserved. In library 4, aromatic residues dominated at position 86 and homologous basic residues, arginine and lysine, dominated at position 99. Position 85, 87 and 95 were also soft randomized, but appeared highly conserved. In library 5, two significant homologous basic residues, lysine and arginine were preferred over glutamine at position 105. Negatively charged residues, aspartic acid or acidic residues, asparagine was dominated at position 110.

**[0148]** We estimated the affinities of some of the mutants by competitive phage ELISA (data not shown), and we found that there were clones in library 3 which were approximately eightfold times better C3b binders than wild type CRIg.

*Determination of in vitro binding affinity and in vivo biological potency*

**[0149]** In order to identify critical residues for increasing the binding affinity to C3b and potency in hemolytic inhibition assay, the next approach was to design second generation of CRlg variants by incorporating dominant single mutation and keep other positions as wild type, or choosing 2-3 high-affinity clones from first generation phage-libraries which were determined by phage ELISA. In order to accurately measure the affinity and potency of our mutants, we expressed all the variants as isolated proteins. The results (Table 3) from hemolytic inhibition assay showed that L12 from library 1, L33 from library 3 and L41 from library 4 significantly increased the potency by 4 to 10 fold compare to wild type in a hemolytic assay. L32 from library 3 showed a 10 fold improved IC50 compared to wild type CRlg. The data also demonstrated that the binding affinity and the potency from the cell-based assays were not correlated.

*Combination of mutants*

**[0150]** Based on the results from the second generation libraries, we designed the third generation of mutants in order to further improve the potency in the hemolytic assay and binding affinity. We chose three of the biologically most potent mutants (L12-8W, L33-Q60I/L32-Q64R and L41-M86Y) and one of the highest binding affinity mutant (L32-Q64R) as a template. Then we combined these mutants with other biological potent clones obtained in the second generation of libraries to determine an optimal set of mutations that increase potency in the hemolytic assay and binding affinity. We expressed and purified the CRlg variants for detailed analysis. The data showed (Table 4) that the combo mutants from L12 didn't improve inhibition potency and even displayed a lower activity compare with the parent mutant despite a 3-6 fold higher binding affinity of the WL41 and WL59 mutants. Within the mutants from L32, RL41 demonstrated a 1.8 fold better binding affinity than wild type and a 6 fold better potency in the hemolytic assay. All the mutants from L33 group showed the significant increased binding affinity; about a 27-226 fold increase compared with wild type although the potency in the hemolysis assay did not increase significantly. We also noticed that 60I-64R and 86Y was involved in most the affinity improved combo clones.

*Improved binding affinity and complement inhibitory activity of CRlg Q64R M86Y mutant*

**[0151]** We selected mutant Q64R M86Y, which had the highest affinity in the competitive ELISA (Fig. 4 and Table 3) for further analysis. In order to determine the binding affinity of CRlg wt and CRlg Q64R M86Y for C3b, Biacore analysis of CRlg wt and CRlg Q64R M86Y was performed. The affinity of CRlg Q64R M86Y was improved 5 fold over wildtype CRlg (Fig. 6). Previous studies have shown that CRlg wt selectively binds to C3b but not to native C3 (Wiesman et al., Nature, 444(7116):217-20, 2006). Since mutagenesis may change this selectivity we compared the affinity of CRlg Q64R M86Y for C3b versus C3 in an alpha-screen fluid-phase competitive assay. CRlg Q64R M86Y competed with soluble C3b, but not with soluble C3, indicating that mutagenesis did not affect the selectivity of CRlg for the active component C3b (Fig. 7). This selectivity was further confirmed by analysis of these residues in the structure of CRlg Q64R M86Y in complex with C3b (data not shown).

**[0152]** To test whether the improved affinity and conserved selectivity for C3b translates into improved efficacy, we tested CRlg Q64R M86Y versus CRlg wt in an erythrocyte-based hemolytic assay selective for the alternative pathway of complement. CRlg Q64R M86Y showed a 4-fold improved IC50 as compared to CRlg wt (Fig. 8A). To further substantiate improved potency toward alternative pathway complement inhibitor, we compared inhibitory activity of CRlg Q64R M86Y with CRlg wt in a LPS-based assay selective for the alternative pathway of complement. Here, CRlg showed a 180-fold improvement in IC50 as compared to the wildtype recombinant protein. CRlg wt and CRlg Q64R M86Y did not affect complement activation through the classical pathway. Thus, a two amino acid substitution in the CRlg-C3b binding interface results in a molecule with improved binding affinity and superior complement inhibitory activity in two different assays with selectivity for the alternative pathway of complement.

**[0153]** To further determine whether increased binding affinity and potency translate into improved therapeutic efficacy, we compared the protective effect of wt and Q64R M86Y version of CRlg in a serum-transfer model of arthritis. Previous studies have shown that CRlg potently inhibits inflammation and bone destruction in collagen- and antibody-induced arthritis (Katschke et al., J. Exp Med 204(6):1319-1325 (2007)).

**[0154]** Here, CRlg efficacy was tested in a third preclinical model of immune complex-mediated arthritis. A spontaneous murine model of rheumatoid arthritis, K/BxN, mimics many of the clinical and histologic features of human disease with arthritis. Mice were injected with 50 microliter serum obtained from K/BxN mice on day 0. Animals were checked daily and the extent of disease was scored by visual observation. All mice were sacrificed on day 6.

**[0155]** Mice were injected subcutaneously with indicated amount of either isotype control or hCRlg-mIgG1 or hCRlg-RL41-mIgG1 recombinant proteins daily in 100ul sterile saline starting on day -1.

**[0156]** Monitoring and scoring:

Score for each paw.

- 0 = No evidence of erythema and swelling
- 1 = Erythema and mild swelling confined to the mid-foot (tarsal) or ankle
- 2 = Erythema and mild swelling extending from the ankle to the mid-foot
- 3 = Erythema and moderate swelling extending from the ankle to the metatarsal joints
- 4 = Erythema and severe swelling encompass the ankle, foot and digits

**[0157]** Mean score = sum of the 4 paw scores.

**[0158]** Disease stages, mild (mean score 1-3), moderate (mean score 4-8) and severe disease (mean score 9-above). The mean score reflects the number of joints involved.

**[0159]** On day 6, blood sample were collected by intracardiac puncture under anesthesia before sacrifice. The amount of hCRlg-Fc fusion proteins will be measured using the serum. Joints were collected for histology evaluation.

**[0160]** Transfer of serum from KRN mice into Balb/c recipients results in a rapid and robust immune response characterized by symmetric inflammation of the joints. Arthritis induction is mediated by anti Glucose-6-phosphate isomerase autoantibodies that form pro-inflammatory immune complexes in the joints (Kouskoff, V., Korganow, A.S., Duchatelle, V., Degott, C., Benoist, C., and Mathis, D. (1996). Organ-specific disease provoked by systemic autoimmunity. Cell 87, 811-822.) Development of arthritis is fully dependent on an intact alternative complement pathway and on Fc receptor function as shown by the lack of disease in mice deficient in alternative pathway complement components and in mice deficient in the common fc-receptor gamma chain (Ji, H., Ohmura, K., Mahmood, U., Lee, D.M., Hofhuis, F.M., Boackle, S.A., Takahashi, K., Holers, V.M., Walport, M., Gerard, C., et al. (2002). Arthritis critically dependent on innate immune system players. Immunity 16, 157-168.) Due to the rapid onset and severity of disease, treatment with CRlg wt-Fc fusion protein reduced arthritis scores by only 22% (Fig. 9A, B). Treatment with CRlg Q64R M86Y showed a reduction in arthritis scores by 66%. Histological examination showed a significant reduction in infiltration of immune cells consisting primarily of neutrophils and macrophages in CRlg Q64R M86Y treated mice versus CRlg wt or control fusion protein-treated mice (Fig. 9C, D). Serum concentrations of CRlg wt and CRlg Q64R M86Y were similar indicating that the difference in arthritis scores was not due to a difference of halflife of the CRlg wt versus CRlg Q64R M86Y protein. Thus, we show that increased binding affinity of CRlg to its target C3b translates into a significantly improved therapeutic efficacy.

**[0161]** While the present invention has been described with reference to what are considered to be the specific embodiments, it is to be understood that the invention is not limited to such embodiments. To the contrary, the invention is intended to cover various modifications and equivalents provided that they are included within the scope of the appended claims.

#### SEQUENCE LISTING

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	gcc	agg	gca	cat	gcc	aga	gag	gcc	aac	gac	tct	gga	gaa	acc	atg	agg	1069
	Ala	Arg	Ala	His	Ala	Arg	Glu	Ala	Asn	Asp	Ser	Gly	Glu	Thr	Met	Arg	
	320					325					330					335	
50	gtg	gcc	atc	ttc	gca	agt	ggc	tgc	tcc	agt	gat	gag	cca	act	tcc	cag	1117
	Val	Ala	Ile	Phe	Ala	Ser	Gly	Cys	Ser	Ser	Asp	Glu	Pro	Thr	Ser	Gln	
					340					345					350		
55	aat	ctg	ggc	aac	aac	tac	tct	gat	gag	ccc	tgc	ata	gga	cag	gag	tac	1165
	Asn	Leu	Gly	Asn	Asn	Tyr	Ser	Asp	Glu	Pro	Cys	Ile	Gly	Gln	Glu	Tyr	
				355					360					365			

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	cag atc atc gcc cag atc aat ggc aac tac gcc cgc ctg ctg gac aca	1213
	Gln Ile Ile Ala Gln Ile Asn Gly Asn Tyr Ala Arg Leu Leu Asp Thr	
	370 375 380	
5	gtt cct ctg gat tat gag ttt ctg gcc act gag ggc aaa agt gtc tgt	1261
	Val Pro Leu Asp Tyr Glu Phe Leu Ala Thr Glu Gly Lys Ser Val Cys	
	385 390 395	
10	taaaaatgcc ccattaggcc aggatctgct gacataatct agagtcgacc tgcagaagct	1321
	tggccgccat ggcccaactt gtttattgca gcttataatg gttacaaata a	1372
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	<213> Homo sapiens	
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# EP 2 280 996 B1

	Met	Gly	Ile	Leu	Leu	Gly	Leu	Leu	Leu	Leu	Gly	His	Leu	Thr	Val	Asp	
	1				5					10					15		
5	Thr	Tyr	Gly	Arg	Pro	Ile	Leu	Glu	Val	Pro	Glu	Ser	Val	Thr	Gly	Pro	
				20					25					30			
10	Trp	Lys	Gly	Asp	Val	Asn	Leu	Pro	Cys	Thr	Tyr	Asp	Pro	Leu	Gln	Gly	
			35					40					45				
15	Tyr	Thr	Gln	Val	Leu	Val	Lys	Trp	Leu	Val	Gln	Arg	Gly	Ser	Asp	Pro	
		50					55					60					
20	Val	Thr	Ile	Phe	Leu	Arg	Asp	Ser	Ser	Gly	Asp	His	Ile	Gln	Gln	Ala	
	65					70					75					80	
25	Lys	Tyr	Gln	Gly	Arg	Leu	His	Val	Ser	His	Lys	Val	Pro	Gly	Asp	Val	
					85					90					95		
30	Ser	Leu	Gln	Leu	Ser	Thr	Leu	Glu	Met	Asp	Asp	Arg	Ser	His	Tyr	Thr	
				100					105					110			
35	Cys	Glu	Val	Thr	Trp	Gln	Thr	Pro	Asp	Gly	Asn	Gln	Val	Val	Arg	Asp	
			115					120					125				
40	Lys	Ile	Thr	Glu	Leu	Arg	Val	Gln	Lys	Leu	Ser	Val	Ser	Lys	Pro	Thr	
		130					135					140					
45	Val	Thr	Thr	Gly	Ser	Gly	Tyr	Gly	Phe	Thr	Val	Pro	Gln	Gly	Met	Arg	
	145					150					155					160	
50	Ile	Ser	Leu	Gln	Cys	Gln	Ala	Arg	Gly	Ser	Pro	Pro	Ile	Ser	Tyr	Ile	
					165					170					175		

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	Trp	Tyr	Lys	Gln	Gln	Thr	Asn	Asn	Gln	Glu	Pro	Ile	Lys	Val	Ala	Thr
				180					185					190		
5	Leu	Ser	Thr	Leu	Leu	Phe	Lys	Pro	Ala	Val	Ile	Ala	Asp	Ser	Gly	Ser
			195					200					205			
10	Tyr	Phe	Cys	Thr	Ala	Lys	Gly	Gln	Val	Gly	Ser	Glu	Gln	His	Ser	Asp
		210					215					220				
15	Ile	Val	Lys	Phe	Val	Val	Lys	Asp	Ser	Ser	Lys	Leu	Leu	Lys	Thr	Lys
	225					230					235					240
20	Thr	Glu	Ala	Pro	Thr	Thr	Met	Thr	Tyr	Pro	Leu	Lys	Ala	Thr	Ser	Thr
					245					250					255	
25	Val	Lys	Gln	Ser	Trp	Asp	Trp	Thr	Thr	Asp	Met	Asp	Gly	Tyr	Leu	Gly
				260					265					270		
30	Glu	Thr	Ser	Ala	Gly	Pro	Gly	Lys	Ser	Leu	Pro	Val	Phe	Ala	Ile	Ile
			275					280					285			
35	Leu	Ile	Ile	Ser	Leu	Cys	Cys	Met	Val	Val	Phe	Thr	Met	Ala	Tyr	Ile
	290						295					300				
40	Met	Leu	Cys	Arg	Lys	Thr	Ser	Gln	Gln	Glu	His	Val	Tyr	Glu	Ala	Ala
	305					310					315					320
45	Arg	Ala	His	Ala	Arg	Glu	Ala	Asn	Asp	Ser	Gly	Glu	Thr	Met	Arg	Val
				325						330					335	
50	Ala	Ile	Phe	Ala	Ser	Gly	Cys	Ser	Ser	Asp	Glu	Pro	Thr	Ser	Gln	Asn
				340					345					350		
55	Leu	Gly	Asn	Asn	Tyr	Ser	Asp	Glu	Pro	Cys	Ile	Gly	Gln	Glu	Tyr	Gln
		355						360					365			
60	Ile	Ile	Ala	Gln	Ile	Asn	Gly	Asn	Tyr	Ala	Arg	Leu	Leu	Asp	Thr	Val
	370						375					380				
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5	gctgtg atg ggg atc tta ctg ggc ctg cta ctc ctg ggg cac cta aca Met Gly Ile Leu Leu Gly Leu Leu Leu Leu Gly His Leu Thr 1 5 10	108
10	gtg gac act tat ggc cgt ccc atc ctg gaa gtg cca gag agt gta aca Val Asp Thr Tyr Gly Arg Pro Ile Leu Glu Val Pro Glu Ser Val Thr 15 20 25 30	156
15	gga cct tgg aaa ggg gat gtg aat ctt ccc tgc acc tat gac ccc ctg Gly Pro Trp Lys Gly Asp Val Asn Leu Pro Cys Thr Tyr Asp Pro Leu 35 40 45	204
20	caa ggc tac acc caa gtc ttg gtg aag tgg ctg gta caa cgt ggc tca Gln Gly Tyr Thr Gln Val Leu Val Lys Trp Leu Val Gln Arg Gly Ser 50 55 60	252
25	gac cct gtc acc atc ttt cta cgt gac tct tct gga gac cat atc cag Asp Pro Val Thr Ile Phe Leu Arg Asp Ser Ser Gly Asp His Ile Gln 65 70 75	300
30	cag gca aag tac cag ggc cgc ctg cat gtg agc cac aag gtt cca gga Gln Ala Lys Tyr Gln Gly Arg Leu His Val Ser His Lys Val Pro Gly 80 85 90	348
35	gat gta tcc ctc caa ttg agc acc ctg gag atg gat gac cgg agc cac Asp Val Ser Leu Gln Leu Ser Thr Leu Glu Met Asp Asp Arg Ser His 95 100 105 110	396
40	tac acg tgt gaa gtc acc tgg cag act cct gat ggc aac caa gtc gtg Tyr Thr Cys Glu Val Thr Trp Gln Thr Pro Asp Gly Asn Gln Val Val 115 120 125	444
45	aga gat aag att act gag ctc cgt gtc cag aaa cac tcc tca aag cta Arg Asp Lys Ile Thr Glu Leu Arg Val Gln Lys His Ser Ser Lys Leu 130 135 140	492
50	ctc aag acc aag act gag gca cct aca acc atg aca tac ccc ttg aaa Leu Lys Thr Lys Thr Glu Ala Pro Thr Thr Met Thr Tyr Pro Leu Lys 145 150 155	540
55	gca aca tct aca gtg aag cag tcc tgg gac tgg acc act gac atg gat Ala Thr Ser Thr Val Lys Gln Ser Trp Asp Trp Thr Thr Asp Met Asp 160 165 170	588
60	ggc tac ctt gga gag acc agt gct ggg cca gga aag agc ctg cct gtc Gly Tyr Leu Gly Glu Thr Ser Ala Gly Pro Gly Lys Ser Leu Pro Val 175 180 185 190	636
65	ttt gcc atc atc ctc atc atc tcc ttg tgc tgt atg gtg gtt ttt acc Phe Ala Ile Ile Leu Ile Ile Ser Leu Cys Cys Met Val Val Phe Thr 195 200 205	684
70	atg gcc tat atc atg ctc tgt cgg aag aca tcc caa caa gag cat gtc Met Ala Tyr Ile Met Leu Cys Arg Lys Thr Ser Gln Gln Glu His Val 210 215 220	732
75	tac gaa gca gcc agg gca cat gcc aga gag gcc aac gac tct gga gaa	780

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	Tyr	Glu	Ala	Ala	Arg	Ala	His	Ala	Arg	Glu	Ala	Asn	Asp	Ser	Gly	Glu	
			225					230					235				
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	Thr	Met	Arg	Val	Ala	Ile	Phe	Ala	Ser	Gly	Cys	Ser	Ser	Asp	Glu	Pro	
		240					245					250					
	act	tcc	cag	aat	ctg	ggc	aac	aac	tac	tct	gat	gag	ccc	tgc	ata	gga	876
10	Thr	Ser	Gln	Asn	Leu	Gly	Asn	Asn	Tyr	Ser	Asp	Glu	Pro	Cys	Ile	Gly	
		255				260					265				270		
	cag	gag	tac	cag	atc	atc	gcc	cag	atc	aat	ggc	aac	tac	gcc	cgc	ctg	924
	Gln	Glu	Tyr	Gln	Ile	Ile	Ala	Gln	Ile	Asn	Gly	Asn	Tyr	Ala	Arg	Leu	
					275					280					285		
15	ctg	gac	aca	gtt	cct	ctg	gat	tat	gag	ttt	ctg	gcc	act	gag	ggc	aaa	972
	Leu	Asp	Thr	Val	Pro	Leu	Asp	Tyr	Glu	Phe	Leu	Ala	Thr	Glu	Gly	Lys	
				290					295					300			
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	Ser	Val	Cys														
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5	Thr	Tyr	Gly	Arg	Pro	Ile	Leu	Glu	Val	Pro	Glu	Ser	Val	Thr	Gly	Pro
				20					25					30		
10	Trp	Lys	Gly	Asp	Val	Asn	Leu	Pro	Cys	Thr	Tyr	Asp	Pro	Leu	Gln	Gly
			35					40					45			
15	Tyr	Thr	Gln	Val	Leu	Val	Lys	Trp	Leu	Val	Gln	Arg	Gly	Ser	Asp	Pro
		50					55					60				
20	Val	Thr	Ile	Phe	Leu	Arg	Asp	Ser	Ser	Gly	Asp	His	Ile	Gln	Gln	Ala
	65					70					75					80
25	Lys	Tyr	Gln	Gly	Arg	Leu	His	Val	Ser	His	Lys	Val	Pro	Gly	Asp	Val
					85					90					95	
30	Ser	Leu	Gln	Leu	Ser	Thr	Leu	Glu	Met	Asp	Asp	Arg	Ser	His	Tyr	Thr
				100					105					110		
35	Cys	Glu	Val	Thr	Trp	Gln	Thr	Pro	Asp	Gly	Asn	Gln	Val	Val	Arg	Asp
40																
45																
50																
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	115	120	125	
5	Lys Ile Thr Glu Leu Arg Val Gln Lys His Ser Ser Lys Leu Leu Lys 130 135 140			
10	Thr Lys Thr Glu Ala Pro Thr Thr Met Thr Tyr Pro Leu Lys Ala Thr 145 150 155 160			
15	Ser Thr Val Lys Gln Ser Trp Asp Trp Thr Thr Asp Met Asp Gly Tyr 165 170 175			
20	Leu Gly Glu Thr Ser Ala Gly Pro Gly Lys Ser Leu Pro Val Phe Ala 180 185 190			
25	Ile Ile Leu Ile Ile Ser Leu Cys Cys Met Val Val Phe Thr Met Ala 195 200 205			
30	Tyr Ile Met Leu Cys Arg Lys Thr Ser Gln Gln Glu His Val Tyr Glu 210 215 220			
35	Ala Ala Arg Ala His Ala Arg Glu Ala Asn Asp Ser Gly Glu Thr Met 225 230 235 240			
40	Arg Val Ala Ile Phe Ala Ser Gly Cys Ser Ser Asp Glu Pro Thr Ser 245 250 255			
45	Gln Asn Leu Gly Asn Asn Tyr Ser Asp Glu Pro Cys Ile Gly Gln Glu 260 265 270			
50	Tyr Gln Ile Ile Ala Gln Ile Asn Gly Asn Tyr Ala Arg Leu Leu Asp 275 280 285			
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	agcttcaaat agg atg gag atc tca tca ggc ttg ctg ttc ctg ggc cac	169
5	Met Glu Ile Ser Ser Gly Leu Leu Phe Leu Gly His 1 5 10	
	cta ata gtg ctc acc tat ggc cac ccc acc cta aaa aca cct gag agt	217
	Leu Ile Val Leu Thr Tyr Gly His Pro Thr Leu Lys Thr Pro Glu Ser 15 20 25	
10	gtg aca ggg acc tgg aaa gga gat gtg aag att cag tgc atc tat gat	265
	Val Thr Gly Thr Trp Lys Gly Asp Val Lys Ile Gln Cys Ile Tyr Asp 30 35 40	
15	ccc ctg aga ggc tac agg caa gtt ttg gtg aaa tgg ctg gta aga cac	313
	Pro Leu Arg Gly Tyr Arg Gln Val Leu Val Lys Trp Leu Val Arg His 45 50 55 60	
20	ggc tct gac tcc gtc acc atc ttc cta cgt gac tcc act gga gac cat	361
	Gly Ser Asp Ser Val Thr Ile Phe Leu Arg Asp Ser Thr Gly Asp His 65 70 75	
	atc cag cag gca aag tac aga ggc cgc ctg aaa gtg agc cac aaa gtt	409
	Ile Gln Gln Ala Lys Tyr Arg Gly Arg Leu Lys Val Ser His Lys Val 80 85 90	
25	cca gga gat gtg tcc ctc caa ata aat acc ctg cag atg gat gac agg	457
	Pro Gly Asp Val Ser Leu Gln Ile Asn Thr Leu Gln Met Asp Asp Arg 95 100 105	
30	aat cac tat aca tgt gag gtc acc tgg cag act cct gat gga aac caa	505
	Asn His Tyr Thr Cys Glu Val Thr Trp Gln Thr Pro Asp Gly Asn Gln 110 115 120	
35	gta ata aga gat aag atc att gag ctc cgt gtt cgg aaa tat aat cca	553
	Val Ile Arg Asp Lys Ile Ile Glu Leu Arg Val Arg Lys Tyr Asn Pro 125 130 135 140	
40	cct aga atc aat act gaa gca cct aca acc ctg cac tcc tct ttg gaa	601
	Pro Arg Ile Asn Thr Glu Ala Pro Thr Thr Leu His Ser Ser Leu Glu 145 150 155	
	gca aca act ata atg agt tca acc tct gac ttg acc act aat ggg act	649
	Ala Thr Thr Ile Met Ser Ser Thr Ser Asp Leu Thr Thr Asn Gly Thr 160 165 170	
45	gga aaa ctt gag gag acc att gct ggt tca ggg agg aac ctg cca atc	697
	Gly Lys Leu Glu Glu Thr Ile Ala Gly Ser Gly Arg Asn Leu Pro Ile 175 180 185	
50	ttt gcc ata atc ttc atc atc tcc ctt tgc tgc ata gta gct gtc acc	745
	Phe Ala Ile Ile Phe Ile Ile Ser Leu Cys Cys Ile Val Ala Val Thr 190 195 200	
	ata cct tat atc ttg ttc cgc tgc agg aca ttc caa caa gag tat gtc	793
	Ile Pro Tyr Ile Leu Phe Arg Cys Arg Thr Phe Gln Gln Glu Tyr Val 205 210 215 220	
55	tat gga gtg agc agg gtg ttt gcc agg aag aca agc aac tct gaa gaa	841
	Tyr Gly Val Ser Arg Val Phe Ala Arg Lys Thr Ser Asn Ser Glu Glu 225 230 235	

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	Thr Thr Arg Val Thr Thr Ile Ala Thr Asp Glu Pro Asp Ser Gln Ala	
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5	ctg att agt gac tac tct gat gat cct tgc ctc agc cag gag tac caa	937
	Leu Ile Ser Asp Tyr Ser Asp Asp Pro Cys Leu Ser Gln Glu Tyr Gln	
	255 260 265	
10	ata acc atc aga tca aca atg tct att cct gcc tgc tgaacacagt	983
	Ile Thr Ile Arg Ser Thr Met Ser Ile Pro Ala Cys	
	270 275 280	
	ttccagaaac taagaagttc ttgctactga agaaaataac atctgctaaa atgcccctac	1043
15	taagtcaagg tctactggcg taattacctg ttacttattt actacttgcc ttcaacatag	1103
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20	ctagcttctg ggcttcaccc agaacaattt tcttcctagg gccttcacaa ctcttctcca	1283
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	cagatgactt ttaattgata ttactattgc tacattatga atctaatagca catgtattct	1463
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5	Thr	Tyr	Gly	His	Pro	Thr	Leu	Lys	Thr	Pro	Glu	Ser	Val	Thr	Gly	Thr
				20					25					30		
10	Trp	Lys	Gly	Asp	Val	Lys	Ile	Gln	Cys	Ile	Tyr	Asp	Pro	Leu	Arg	Gly
			35					40					45			
15	Tyr	Arg	Gln	Val	Leu	Val	Lys	Trp	Leu	Val	Arg	His	Gly	Ser	Asp	Ser
		50					55					60				
20	Val	Thr	Ile	Phe	Leu	Arg	Asp	Ser	Thr	Gly	Asp	His	Ile	Gln	Gln	Ala
	65					70					75					80
25	Lys	Tyr	Arg	Gly	Arg	Leu	Lys	Val	Ser	His	Lys	Val	Pro	Gly	Asp	Val
					85					90					95	
30																
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55																

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	Ser	Leu	Gln	Ile	Asn	Thr	Leu	Gln	Met	Asp	Asp	Arg	Asn	His	Tyr	Thr	
				100					105					110			
5	Cys	Glu	Val	Thr	Trp	Gln	Thr	Pro	Asp	Gly	Asn	Gln	Val	Ile	Arg	Asp	
			115					120					125				
	Lys	Ile	Ile	Glu	Leu	Arg	Val	Arg	Lys	Tyr	Asn	Pro	Pro	Arg	Ile	Asn	
10		130					135					140					
	Thr	Glu	Ala	Pro	Thr	Thr	Leu	His	Ser	Ser	Leu	Glu	Ala	Thr	Thr	Ile	
	145					150					155					160	
15	Met	Ser	Ser	Thr	Ser	Asp	Leu	Thr	Thr	Asn	Gly	Thr	Gly	Lys	Leu	Glu	
					165					170					175		
	Glu	Thr	Ile	Ala	Gly	Ser	Gly	Arg	Asn	Leu	Pro	Ile	Phe	Ala	Ile	Ile	
20				180					185					190			
	Phe	Ile	Ile	Ser	Leu	Cys	Cys	Ile	Val	Ala	Val	Thr	Ile	Pro	Tyr	Ile	
25			195					200					205				
	Leu	Phe	Arg	Cys	Arg	Thr	Phe	Gln	Gln	Glu	Tyr	Val	Tyr	Gly	Val	Ser	
		210					215					220					
30	Arg	Val	Phe	Ala	Arg	Lys	Thr	Ser	Asn	Ser	Glu	Glu	Thr	Thr	Arg	Val	
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	Thr	Thr	Ile	Ala	Thr	Asp	Glu	Pro	Asp	Ser	Gln	Ala	Leu	Ile	Ser	Asp	
35					245					250					255		
	Tyr	Ser	Asp	Asp	Pro	Cys	Leu	Ser	Gln	Glu	Tyr	Gln	Ile	Thr	Ile	Arg	
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<223> see specification as filed for detailed description of substitutions and preferred embodiments

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Thr

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<220>

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Leu Glu Cys Asp Asp Gln Ser His Tyr Thr Cys Glu Val Thr Trp Tyr  
1 5 10 15

55

Thr

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              Thr

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30           Thr

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<400> 38

40           Leu Glu Tyr Asp Asp Arg Ser His Tyr Thr Cys Glu Val Thr Trp Lys  
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<210> 43

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# EP 2 280 996 B1

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Thr

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Thr

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Thr

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# EP 2 280 996 B1

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1 5 10 15

5 Thr

<210> 47

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20 Thr

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35 Thr

<210> 49

40 <211> 17

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45 <223> Description of Artificial Sequence: Synthetic peptide

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50 Thr

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<223> Lys or Arg

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Thr

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<213> Unknown

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<210> 52

<211> 8

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<400> 53

# EP 2 280 996 B1

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<210> 58  
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1 5

<210> 59  
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1 5

<210> 60  
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<210> 61  
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Asn Lys Val Thr Arg Asp Asn Ile  
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<210> 62  
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# EP 2 280 996 B1

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Asn Lys Val Val Arg Asp Gln Ile  
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<210> 63

<211> 8

<212> PRT

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<210> 64

<211> 8

<212> PRT

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<210> 65

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<210> 66

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## Claims

1. A CRIg variant comprising an amino acid substitution at one or more amino acid positions selected from the group consisting of positions 8, 14, 18, 42, 44, 45, 60, 64, 86, 99, 105, and 110 in the amino acid sequence of SEQ ID NO: 2, which has at least 2-fold increased binding affinity to C3b over native sequence human CRIg of SEQ ID NO: 2, and/or which is at least a 2-fold more potent inhibitor of the alternative complement pathway than native sequence human CRIg of SEQ ID NO: 2.
2. The variant of claim 1 which selectively binds to C3b over C3, or a fragment thereof.
3. The variant of claim 1 wherein the binding affinity and/or potency of inhibition is increased by at least 5 fold.
4. The variant of claim 1 wherein the binding affinity and/or potency of inhibition is increased by at least 10 fold.
5. The variant of claim 1 wherein the binding affinity is increased by at least 90 fold.
6. The variant of claim 1 comprising an amino acid substitution at one or more of amino acid positions 60, 64, 86, 99, 105 and 110 in the amino acid sequence of SEQ ID NO: 2.
7. The variant of claim 1 comprising:
  - (i) one or more substitutions selected from the group consisting of E8W, W14F, E8Y/W14F; P45F; G42D/D44H/P45F; Q60I; Q64R; Q60I/Q64R; M86Y; M86W, M86F, M86W/Q99R; M86F/Q99R; K110D, K110N; Q105R/K110N; Q105R/K110Q; and Q105K/K110D; or
  - (ii) one or more substitutions selected from the group consisting of Q64R/M86Y; Q60I/Q64R/E8Y; Q60I/Q64R/G42D; Q60I/Q64R/P45F; Q60I/Q64R/G42D/D44H/P45F; Q60I/Q64R/M86Y; Q60I/Q64R/Q105R; Q60I/Q64R/Q105K; Q60I/Q64R/K110N; Q60I/Q105R/K110N; M86Y/E8Y; M86Y/G42D/D44H/P45F; M86Y/P45F; M86Y/G42D/D44H/P45F; and M86Y/Q99K/M86Y/Q99R/M86Y/Q105R/M86Y/Q105K/M86Y/Q105R/K110N; or
  - (iii) one or more substitutions selected from the group consisting of Q60I; Q64R; Q60I/Q64R; M86Y; Q99L;

Q105K/K110D; E8W/Q105R/K110N; Q64R/M86Y; Q60I/Q64R/E8Y; Q60I/Q64R/G42D; Q60I/Q64R/P45F; Q60I/Q64R/G42D/D44H/P45F; Q60I/Q64R/M86Y; Q60I/Q64R/Q105R; Q60I/Q64R/Q105K; Q60I/Q64R/K110N; M86Y/P45F; and M86Y/Q105K; or  
(iv) a Q60I/Q64R/M86Y or Q60I/Q64R/G42D/D44H/P45F substitution.

8. A chimeric molecule comprising a variant according to any one of claims 1 to 7.
9. The chimeric molecule of claim 8 which is an immunoadhesin.
10. The chimeric molecule of claim 9 wherein said CRIg variant is shorter than the full-length CRIg of SEQ ID NO: 2.
11. The chimeric molecule of claim 10 comprising a CRIg extracellular domain.
12. A pharmaceutical composition comprising a CRIg variant according to any one of claims 1 to 7, or a chimeric molecule according to claim 8, or an immunoadhesin according to any one of claims 9 to 11, in admixture with a pharmaceutically acceptable excipient.
13. A CRIg variant according to any one of claims 1 to 7, or a chimeric molecule according to claim 8, or an immunoadhesin according to any one of claims 9 to 11, for use in a method of medical treatment.
14. The CRIg variant, chimeric molecule, or immunoadhesin according to claim 13, for use in a method for the prevention or treatment of a complement-associated disease or condition.
15. The CRIg variant, chimeric molecule, or immunoadhesin according to claim 13 for use of claim 14 wherein said complement-associated disease is:
  - (i) an inflammatory disease or an autoimmune disease; or
  - (ii) selected from the group consisting of rheumatoid arthritis (RA), adult respiratory distress syndrome (ARDS), remote tissue injury after ischemia and reperfusion, complement activation during cardiopulmonary bypass surgery, dermatomyositis, pemphigus, lupus nephritis and resultant glomerulonephritis and vasculitis, cardiopulmonary bypass, cardioplegia-induced coronary endothelial dysfunction, type II membranoproliferative glomerulonephritis, IgA nephropathy, acute renal failure, cryoglobulemia, antiphospholipid syndrome, age-related macular degeneration, uveitis, diabetic retinopathy, allo-transplantation, hyperacute rejection, hemodialysis, chronic occlusive pulmonary distress syndrome (COPD), asthma, aspiration pneumonia, urticaria, chronic idiopathic urticaria, hemolytic uremic syndrome, endometriosis, cardiogenic shock, ischemia reperfusion injury, and multiple sclerosis (MS); or
  - (iii) selected from the group consisting of inflammatory bowel disease (IBD), systemic lupus erythematosus, rheumatoid arthritis, juvenile chronic arthritis, spondyloarthropathies, systemic sclerosis (scleroderma), idiopathic inflammatory myopathies (dermatomyositis, polymyositis), Sjogren's syndrome, systemic vaculitis, sarcoidosis, autoimmune hemolytic anemia (immune pancytopenia, paroxysmal nocturnal hemoglobinuria), autoimmune thrombocytopenia (idiopathic thrombocytopenic purpura, immune-mediated thrombocytopenia), thyroiditis (Grave's disease, Hashimoto's thyroiditis, juvenile lymphocytic thyroiditis, atrophic thyroiditis), diabetes mellitus, immune-mediated renal disease (glomerulonephritis, tubulointerstitial nephritis), demyelinating diseases of the central and peripheral nervous systems such as multiple sclerosis, idiopathic polyneuropathy, hepatobiliary diseases such as infectious hepatitis (hepatitis A, B, C, D, E and other nonhepatotropic viruses), autoimmune chronic active hepatitis, primary biliary cirrhosis, granulomatous hepatitis, and sclerosing cholangitis, inflammatory and fibrotic lung diseases (e.g., cystic fibrosis), gluten-sensitive enteropathy, Whipple's disease, autoimmune or immune-mediated skin diseases including bullous skin diseases, erythema multiforme and contact dermatitis, psoriasis, allergic diseases of the lung such as eosinophilic pneumonia, idiopathic pulmonary fibrosis and hypersensitivity pneumonitis, transplantation associated diseases including graft rejection, graft-versus host disease, Alzheimer's disease, paroxysmal nocturnal hemoglobinurea, hereditary angioedema, atherosclerosis and type II membranoproliferative glomerulonephritis; or
  - (iv) rheumatoid arthritis (RA); or
  - (v) a complement-associated eye condition, wherein said complement-associated eye condition is optionally selected from the group consisting of all stages of age-related macular degeneration (AMD), uveitis, diabetic and other ischemia-related retinopathies, endophthalmitis, and other intraocular neovascular diseases, and wherein the intraocular neovascular disease is optionally selected from the group consisting of diabetic macular edema, pathological myopia, von Hippel-Lindau disease, histoplasmosis of the eye, Central Retinal Vein Oc-



clusion (CRVO), corneal neovascularization, and retinal neovascularization.

16. The CRlg variant, chimeric molecule, or immunoadhesin according to claim 13 for use of claim 15 part (v) wherein said complement-associated eye condition is selected from the group consisting of age-related macular degeneration (AMD), choroidal neovascularization (CNV), diabetic retinopathy (DR), and endophthalmitis.
17. The CRlg variant, chimeric molecule, or immunoadhesin according to claim 13 for use of claim 16 wherein said AMD is wet AMD.
18. The CRlg variant, chimeric molecule, or immunoadhesin according to claim 13 for use of claim 16 wherein said AMD is dry or atrophic AMD.
19. The CRlg variant, chimeric molecule, or immunoadhesin according to claim 13 for use of claim 14 wherein said subject is a mammal, and wherein said mammal is optionally a human.

### Patentansprüche

1. CRlg-Variante, die eine Aminosäuresubstitution an einer oder mehreren Aminosäurepositionen umfasst, die aus der aus den Positionen 8, 14, 18, 42, 44, 45, 60, 64, 86, 99, 105 und 110 in der Aminosäuresequenz der Seq.-ID Nr. 2 bestehenden Gruppe ausgewählt sind, die zumindest eine 2-mal höhere Bindungsaffinität an C3b aufweist als menschliches CRlg der Seq.-ID Nr. 2 mit nativer Sequenz und/oder die zumindest ein 2-mal stärkerer Inhibitor des Alternativ-Komplement-Wegs ist als menschliches CRlg der Seq.-ID Nr. 2 mit nativer Sequenz.
2. Variante nach Anspruch 1, die selektiv an C3b gegenüber C3 bindet, oder ein Fragment davon.
3. Variante nach Anspruch 1, wobei die Bindungsaffinität und/oder Hemmpotenz um zumindest das 5-fache erhöht ist.
4. Variante nach Anspruch 1, wobei die Bindungsaffinität und/oder Hemmpotenz um zumindest das 10-fache erhöht ist.
5. Variante nach Anspruch 1, wobei die Bindungsaffinität um zumindest das 90-fache erhöht ist.
6. Variante nach Anspruch 1, die eine Aminosäuresubstitution an einer oder mehreren der Aminosäurepositionen 60, 64, 86, 99, 105 und 110 in der Aminosäuresequenz der Seq.-ID Nr. 2 umfasst.
7. Variante nach Anspruch 1, die Folgendes umfasst:
  - (i) eine oder mehrere Substitutionen, die aus der aus E8W, W14F, E84Y/W14F; P45F; G42D/D44H/P45F; Q60I; Q64R; Q60I/Q64R; M86Y; M86W, M86F, M86W/Q99R; M86F/Q99R; K110D, K110N; Q105R/K110Q; und Q105K/K110D bestehenden Gruppe ausgewählt sind; oder
  - (ii) eine oder mehrere Substitutionen, die aus der aus Q64R/M86Y; Q60I/Q64R/E8Y; Q60I/Q64R/G42D; Q60I/Q64R/P45F; Q60I/Q64R/G42D/D44H/P45F; Q60I/Q64R/M86Y; Q60I/Q64R/Q105R; Q60I/Q64R/Q105K; Q60I/Q64R/K110N; Q60I/Q105R/K110N; M86Y/E8Y; M86Y/G42D/D44H/P45F; M86Y/P45F; M86Y/G42D/D44H/P45F bestehenden Gruppe ausgewählt sind; und M86Y/Q99R/M86Y/Q99R/M86Y/Q105R/M86Y/Q105K/M86Y/Q105R/K110N; oder
  - (iii) eine oder mehrere Substitutionen, die aus der aus Q60I; Q64R; Q60I/Q64R; M86Y; Q99L; Q105K/K110D; E8W/Q105R/K110N; Q64R/M86Y; Q60I/Q64R/E8Y; Q60I/Q64R/G42D; Q60I/Q64R/P45F; Q60I/Q64R/G42D/D44H/P45F; Q60I/Q64R/M86Y; Q60I/Q64R/Q105R; Q60I/Q64R/Q105K; Q60I/Q64R/K110N; M86Y/P45F; und M86Y/Q105K bestehenden Gruppe ausgewählt sind; oder
  - (iv) eine Q60I/Q64R/M86Y- oder Q60I/Q64R/G42D/D44H/P45F-Substitution.
8. Chimäres Molekül, das eine Variante nach einem der Ansprüche 1-7 umfasst.
9. Chimäres Molekül nach Anspruch 8, das ein Immunadhesin ist.
10. Chimäres Molekül nach Anspruch 9, wobei die CRlg-Variante kürzer ist als das CRlg der Seq.-ID Nr. 2 voller Länge.

11. Chimäres Molekül nach Anspruch 10, das eine extrazelluläre CRlg-Domäne umfasst.
12. Pharmazeutische Zusammensetzung, die eine CRlg-Variante nach einem der Ansprüche 1 bis 7 oder ein chimäres Molekül nach Anspruch 8 oder ein Immunadhäsion nach einem der Ansprüche 9 bis 11 in einem Gemisch mit einem pharmazeutisch annehmbaren Exzipienten umfasst.
13. CRlg-Variante nach einem der Ansprüche 1 bis 7 oder chimäres Molekül nach Anspruch 8 oder Immunadhäsion nach einem der Ansprüche 9 bis 11 zur Verwendung in einem medizinischen Behandlungsverfahren.
14. CRlg-Variante, chimäres Molekül oder Immunadhäsion nach Anspruch 13 zur Verwendung in einem Verfahren zur Vorbeugung oder Behandlung einer/s komplementassoziierten Erkrankung oder Leidens.
15. CRlg-Variante, chimäres Molekül oder Immunadhäsion nach Anspruch 13 zur Verwendung nach Anspruch 14, wobei die komplementassoziierte Erkrankung Folgendes ist:
- (i) eine Entzündungserkrankung oder eine Autoimmunerkrankung; oder
  - (ii) aus der aus rheumatoider Arthritis (RA), Atemnotsyndrom des Erwachsenen (ARDS), entfernten Gewebsverletzungen nach einer Ischämie und Reperfusion, Komplementaktivierung während einer kardiopulmonalen Bypassoperation, Dermatomyositis, Pemphigus, Lupus nephritis und resultierender Glomerulonephritis und Vaskulitis, kardiopulmonalem Bypass, durch Kardioplegie induzierter koronarer endothelialer Dysfunktion, membranoproliferativer Glomerulonephritis vom Typ II, IgA-Nephropathie, akutem Nierenversagen, Kryoglobulinämie, Antiphospholipid-Syndrom, altersbedingter Makuladegeneration, Uveitis, diabetischer Retinopathie, Allotransplantation, hyperakuter Abstoßung, Hämodialyse, chronisch-okklusiver Lungenerkrankung (COPD), Asthma, Aspirationspneumonie, Urtikaria, chronischer idiopathischer Urtikaria, hämolytisch-urämischem Syndrom, Endometriose, kardiogenem Schock, Ischämie-Reperusions-Schaden und multipler Sklerose (MS) bestehenden Gruppe ausgewählt ist; oder
  - (iii) aus der aus entzündlicher Darmerkrankung (IBD), systemischem Lupus erythematoses, rheumatoider Arthritis, juveniler chronischer Arthritis, Spondyloarthropathien, systemischer Sklerose (Sklerodermie), idiopathischen inflammatorischen Myopathien (Dermatomyositis, Polymyositis), Sjögren-Syndrom, systemischer Vaskulitis, Sarkoidose, autoimmuner hämolytischer Anämie (Immunpanzytopenie, paroxysmale nächtliche Hämoglobinurie), autoimmuner Thrombozytopenie (idiopathische thrombozytopenische Purpura, immunvermittelte Thrombozytopenie), Thyreoiditis (Morbus Basedow, Hashimoto-Thyreoiditis, juvenile lymphozytäre Thyreoiditis, atrophische Thyreoiditis), Diabetes mellitus, immunvermittelter Nierenerkrankung (Glomerulonephritis, tubulo-interstitielle Nephritis), Entmarkungserkrankungen des Zentral- und peripheren Nervensystems, wie z.B. multiple Sklerose, idiopathischer Polyneuropathie, hepatobiliären Erkrankungen, wie z.B. infektiöser Hepatitis (Hepatitis A, B, C, D, E und andere nichtheepatotrope Viren), chronisch aktiver Autoimmunhepatitis, primärer biliärer Zirrhose, granulomatöser Hepatitis und sklerosierender Cholangitis, entzündlichen und fibrotischen Lungenerkrankungen (z.B. zystische Fibrose), glutensensitive Enteropathie, Morbus Whipple, Autoimmun- oder immunvermittelten Hauterkrankungen, einschließlich bullöser Hauterkrankungen, Erythema multiforme und Kontaktdermatitis, Psoriasis, allergischen Erkrankungen der Lunge, wie z.B. eosinophile Pneumonie, idiopathische Lungenfibrose und Hypersensitivitätspneumonitis, mit einer Transplantation assoziierten Erkrankungen, einschließlich Transplantatabstoßung, Transplantat-gegen-Wirt-Erkrankung, Alzheimer-Krankheit, paroxysmaler nächtlicher Hämoglobinurie, hereditären Angioödem, Atherosklerose und membranoproliferativer Glomerulonephritis vom Typ II bestehenden Gruppe ausgewählt ist; oder
  - (iv) rheumatoide Arthritis (RA); oder
  - (v) ein komplementassoziiertes Augenleiden, wobei das komplementassoziierte Augenleiden gegebenenfalls aus der aus allen Stufen von altersbezogener Makuladegeneration (AMD), Uveitis, diabetischen und anderen mit Ischämie zusammenhängenden Retinopathien, Endophthalmitis und anderen intraokularen neovaskulären Erkrankungen bestehenden Gruppe ausgewählt ist, und wobei die intraokulare neovaskuläre Erkrankung gegebenenfalls aus der aus diabetischen Makulaödem, pathologischer Myopie, Hippel-Lindau-Erkrankung, Histoplasmose des Auges, zentralem retinalem Venenverschluss (CRVO), Hornhautneovaskularisation und Retinaneovaskularisation bestehenden Gruppe ausgewählt ist.
16. CRlg-Variante, chimäres Molekül oder Immunadhäsion nach Anspruch 13 zur Verwendung nach Anspruch 15 Teil (v), wobei das komplementassoziierte Augenleiden aus der aus altersbedingter Makuladegeneration (AMD), choroïdaler Neovaskularisation (CNV), diabetischer Retinopathie (DR) und Endophthalmitis bestehenden Gruppe ausgewählt ist.

17. CRlg-Variante, chimères Molekül oder Immunadhäsine nach Anspruch 13 zur Verwendung nach Anspruch 16, wobei die AMD feuchte AMD ist.

18. CRlg-Variante, chimères Molekül oder Immunadhäsine nach Anspruch 13 zur Verwendung nach Anspruch 16, wobei die AMD trockene oder atrophe AMD ist.

19. CRlg-Variante, chimères Molekül oder Immunadhäsine nach Anspruch 13 zur Verwendung nach Anspruch 14, wobei das Individuum ein Säugetier ist und wobei das Säugetier gegebenenfalls ein Mensch ist.

## Revendications

1. Variant de CRlg comprenant une substitution d'acide aminé à une ou plusieurs positions d'acides aminés choisies dans le groupe consistant en les positions 8, 14, 18, 42, 44, 45, 60, 64, 86, 99, 105 et 110 dans la séquence d'acides aminés de la SEQ ID N° 2, qui a une affinité de liaison augmentée au moins d'un facteur 2 pour C3b par rapport à la CRlg humaine à séquence naturelle de la SEQ ID N° 2, et/ou qui est un inhibiteur au moins 2 fois plus puissant de la voie du complément alternative par rapport à la CRlg humaine à séquence naturelle de la SEQ ID N° 2.

2. Variant suivant la revendication 1, qui se lie sélectivement à C3b par rapport à C3, ou un de ses fragments.

3. Variant suivant la revendication 1, dans lequel l'affinité de liaison et/ou la puissance d'inhibition est augmentée au moins d'un facteur 5.

4. Variant suivant la revendication 1, dans lequel l'affinité de liaison et/ou la puissance d'inhibition est augmentée au moins d'un facteur 10.

5. Variant suivant la revendication 1, dans lequel l'affinité de liaison est augmentée au moins d'un facteur 90.

6. Variant suivant la revendication 1, comprenant une substitution d'acide aminé à une ou plusieurs positions d'acides aminés 60, 64, 86, 99, 105 et 110 dans la séquence d'acides aminés de la SEQ ID N° 2.

7. Variant suivant la revendication 1, comprenant :

(i) une ou plusieurs substitutions choisies dans le groupe consistant en E8W, W14F, E84Y/W14F ; P45F ; G42D/D44H/P45F ; Q60I ; Q64R ; Q60I/Q64R ; M86Y ; M86W, M86F, M86W/Q99R ; M86F/Q99R ; K110D, K110N ; Q105R/K110N ; Q105R/K110Q ; et Q105K/K110D ; ou

(ii) une ou plusieurs substitutions choisies dans le groupe consistant en Q64R/M85Y ; Q60I/Q64R/E8Y ; Q60I/Q64R/G42D ; Q60I/Q64R/P45F ; Q60I/Q64R/G42D/D44H/P45F ; Q60I/Q64R/M86Y ; Q60I/Q64R/Q105R ; Q60I/Q64R/Q105K ; Q60I/Q64R/K110N ; Q60I/Q105R/K110N ; M86Y/E8Y ; M86Y/G42D/D44H/P45F ; M86Y/P45F ; M86Y/G42D/D44H/P45F ; et M86Y/Q99R/M86Y/Q99R/M86Y/Q105R/M86Y/Q105K/M86Y/Q105R/K110N ; ou

(iii) une ou plusieurs substitutions choisies dans le groupe consistant en Q60I ; Q64R ; Q60I/Q64R ; M86Y ; Q99L ; Q105K/K110D ; E8W/Q105R/K110N ; Q64R/M86Y ; Q60I/Q64R/E8Y ; Q60I/Q64R/G42D ; Q60I/Q64R/P45F ; Q60I/Q64R/G42D/D44H/P45F ; Q60I/Q64R/M86Y ; Q60I/Q64R/Q105R ; Q60I/Q64R/Q105K ; Q60I/Q64R/K110N ; M86Y/P45F ; et M86Y/Q105K ; ou

(iv) une substitution Q60I/Q64R/M86Y ou Q60I/Q64R/G42D/D44H/P45F.

8. Molécule chimère comprenant un variant suivant l'une quelconque des revendications 1 à 7.

9. Molécule chimère suivant la revendication 8, qui est une immunoadhésine.

10. Molécule chimère suivant la revendication 9, dans lequel ledit variant de CRlg est plus court que la CRlg complète de la SEQ ID N° 2.

11. Molécule chimère suivant la revendication 10, comprenant un domaine extracellulaire de CRlg.

12. Composition pharmaceutique comprenant un variant suivant l'une quelconque des revendications 1 à 7, ou une molécule chimère suivant la revendication 8, ou bien une immunoadhésine suivant l'une quelconque des revendications 9 à 11, en mélange avec un excipient pharmaceutiquement acceptable.

13. Variant de CRlg suivant l'une quelconque des revendications 1 à 7, ou molécule chimère suivant la revendication 8, ou bien immunoadhésine suivant l'une quelconque des revendications 9 à 11, pour une utilisation dans un procédé de traitement médical.

14. Variant de CRlg, molécule chimère ou immunoadhésine suivant la revendication 13, pour une utilisation dans un procédé pour la prévention ou le traitement d'une maladie ou affection associée au complément.

15. Variant de CRlg, molécule chimère ou immunoadhésine suivant la revendication 13, pour une utilisation suivant la revendication 14, ladite maladie associée au complément étant :

(i) une maladie inflammatoire ou une maladie autoimmune ; ou

(ii) une maladie choisie dans le groupe consistant en la polyarthrite rhumatoïde (PR), le syndrome de détresse respiratoire de l'adulte (SDRA), une lésion tissulaire éloignée après une ischémie et une reperfusion ; l'activation du complément au cours d'une intervention chirurgicale de dérivation cardio-pulmonaire, la dermatomyosite, le pemphigus, la névrite du lupus et la glomérulonéphrite et la vasculite résultantes, une dérivation cardio-pulmonaire, un dysfonctionnement endothélial coronarien induit par cardioplégie, la glomérulonéphrite membranoproliférative de type II, la néphropathie à IgA, l'insuffisance rénale aiguë, la cryoglobulémie, le syndrome des antiphospholipides, la dégénérescence maculaire due à l'âge, l'uvéite, la rétinopathie diabétique, une allo-transplantation, un rejet hyperaigu, l'hémodialyse, le syndrome de détresse pulmonaire occlusive chronique (BPCO), l'asthme, la pneumonie par aspiration, l'urticaire, l'urticaire idiopathique chronique, le syndrome urémique hémolytique, l'endométriome, un choc cardiogène, une lésion de reperfusion ischémique et la sclérose en plaques (SEP) ; ou

(iii) une maladie choisie dans le groupe consistant en une maladie intestinale inflammatoire (IBD), le lupus érythémateux disséminé, la polyarthrite rhumatoïde, l'arthrite chronique juvénile, des spondyloarthropathies, la sclérose généralisée (sclérodermie), les myopathies inflammatoires idiopathiques (dermatomyosite, polymyosite), le syndrome de Sjögren, la vasculite généralisée, la sarcoïdose, l'anémie hémolytique auto-immune (pancytopénie immunitaire, hémoglobinurie nocturne paroxystique), la thrombocytopénie auto-immune (purpura thrombocytopénique idiopathique, thrombocytopénie à médiation immunitaire), la thyroïdite (maladie de Grave, thyroïdite de Hashimoto, thyroïde lymphocytaire juvénile, thyroïdite atrophique), le diabète sucré, une maladie rénale à médiation immunitaire (glomérulonéphrite, néphrite tubulo-interstitielle), des maladies démyélinisantes du système nerveux central et du système nerveux périphérique telles que la sclérose en plaques, la polyneuropathie idiopathique, des maladies hépatobiliaires telles que l'hépatite infectieuse (hépatites A, B, D, E et par d'autres virus non hépatotropes), l'hépatite active chronique auto-immune, la cirrhose biliaire primaire, l'hépatite granulomateuse, et la cholangite sclérosante, des maladies pulmonaires inflammatoires et fibrotiques (par exemple la fibrose kystique), l'entéropathie sensible au gluten, la maladie de Whipple, des maladies cutanées auto-immunes ou à médiation immunitaire comprenant des maladies cutanées bulleuses, l'érythème multiforme et la dermatite de contact, le psoriasis, des maladies allergiques du poumon telles que la pneumonie éosinophile, la fibrose pulmonaire idiopathique et la pneumonie d'hypersensibilité, des maladies associées à une transplantation comprenant le rejet d'un greffon, la réaction du greffon contre l'hôte, la maladie d'Alzheimer, l'hémoglobulinurie nocturne paroxystique, l'angio-oedème héréditaire, l'athérosclérose et la glomérulonéphrite membranoproliférative de type II ; ou

(iv) la polyarthrite rhumatoïde (PR) ; ou

(v) une affection ophtalmique associée au complément, ladite affection ophtalmique associée au complément étant choisie éventuellement dans le groupe consistant en tous les stades de la dégénérescence maculaire due à l'âge (DMLA), l'uvéite, la rétinopathie diabétique et d'autres rétinopathies en rapport avec une ischémie, l'endophtalmie et d'autres maladies néovasculaires intraoculaires, ladite maladie néovasculaire intraoculaire étant choisie éventuellement dans le groupe consistant en l'oedème maculaire diabétique, la myopie pathologique, la maladie de von Hippel-Lindau, l'histioplasmose oculaire, l'occlusion d'une veine rétinienne centrale (CRVO), la néovascularisation cornéenne et la néovascularisation rétinienne.

16. Variant de CRlg, molécule chimère ou immunoadhésine suivant la revendication 13, pour une utilisation suivant la partie (v) de la revendication 15, ladite affection ophtalmique associée au complément étant choisie dans le groupe consistant en la dégénérescence maculaire due à l'âge (DMLA), la néovascularisation choroïdienne (NVC), la rétinopathie diabétique (RD) et l'endophtalmie.

**17.** Variant de CRlg, molécule chimère ou immunoadhésine suivant la revendication 13, pour une utilisation suivant la revendication 16, ladite DMLA étant la DMLA humide.

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**18.** Variant de CRlg, molécule chimère ou immunoadhésine suivant la revendication 13, pour une utilisation suivant la revendication 16, ladite DMLA étant la DMLA sèche ou atrophique.

**19.** Variant de CRlg, molécule chimère ou immunoadhésine suivant la revendication 13, pour une utilisation suivant la revendication 14, ledit sujet étant un mammifère, et ledit mammifère étant éventuellement un être humain.

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1 CCAACTGCAC CTGGTTCTA TCGATAGGAG GCTGGAAGAA AGGACAGAAG TAGCTCTGGG ATCTTACTGG GCCTGTACT CCTGGGGCAC  
 GGTGACGTG GAGCCAAGAT AGCTATCCTC CGACCTTCTT TCTGTCTTC ATCGAGACCG ACACTACCCC TAGAATGACC CGGACGATGA GGACCCCGTC  
 1 M G I L L G L L L L G H  
 ^MET  
 101 CTACAGTGG ACACCTAATG CGGTCCCATC CTGGAAGTGC CAGAGAGTGT AACAGGACCT TGGAAAGGGG ATGTGAATCT TCCCTGCACC TATGACCCCC  
 GATTGCACC TGTGAATACC GGCAGGGTAG GACCTTCAAG GTCTCTACA TTGTCTTCCA ACCTTTCCCC TACACTTAGA AGGAGGTGG ATACTGGGGG  
 13 L T V D T Y G R P I L E V P E S V T G P W K G D V N L P C T Y D P L  
 201 TCGAAGGCTA CACCCAAGTC TTGGTGAAGT GGTGGTACA AGTGGCTCA GACCTTTCT CCATCTTTCT ACGTGACTCT TCTGGAGACC ATATCCAGCA  
 ACGTTCGGAT GTGGTTTCA ACCACTTCA CCGACCATGT TGCACCGAGT CTGGGACAGT GGTAGAAGA TGCACCTGAGA AGACCTCTGG TATAGTCTGT  
 47 Q G Y T Q V L V K W L V Q R G S D P V T I F L R D S S G D H I Q Q  
 301 GGCAAGTAC CAGGGCCGCC TGCATGTGAG CCACAAGGT CCAGGAGATG TATCCCTCCA ATTGAGCACC CTGGAGATGG ATGACCGGAG CCACTACAG  
 CCGTTTCATG GTCCCGGGG ACGTACACTC GGTGTTCCTAC ATAGGGAGGT TAACTGTGG GACCTCTACC TACTGGCCTC GGTGATGTGC  
 80 A K Y Q G R L H V S H K V P G D V S L Q L S T L E M D D R S H Y T  
 401 TGTGAAGTCA CCTGGCAGAC TCCTGATGGC AACCAAGTGG TGAGAGATAA GATTACTGAG CTCGGTGTCC AGAAACTCTC TGTCTCCAAG CCCACAGTGA  
 ACACCTTCAG GGACCGTCTG AGGACTACCG TTGGTTCAGC ACTCTCTATT CTAATGACTC GAGGCACAGG TCTTTGAGAG ACAGAGGTTT GGGTGTCACT  
 113 C E V T W Q T P D G N Q V V R D K I T E L R V Q K L S V S K P T V T  
 501 CAACCTGGCAG CGGTATGCG TTACCGTGC CCGAGGGAAT GAGGATTAGC CTTCAATGCC AGGCTCGGG TTCTCTCTCC ATCAGTTATA TTGGTATAA  
 GTTGACCGTC GCCAATACCG AAGTGGCAGG GGGTCCCTTA CTCCTAATCG GAAGTTACCG TCCGAGCCCC AAGAGGAGGG TAGTCAATAT AAACCATATT  
 147 T G S G Y G F T V P Q G M R I S L Q C Q A R G S P P I S Y I W Y K

FIG. 1A

601 GCAACAGACT AATAACCAGG AACCCATCAA AGTAGCAACC CTAAGTACCT TACICITCAA GCGTGGGIG ATAGCGACT CAGGCTCCTA TTTCGGACT  
 CGTTGCTGA TTATGGTCC TTGGTAGTT TCATCGTGG GATTATGGA ATGAGAGTT CCGACGCCAC TATCGGTGA GTCCGAGGAT AAAGACGTGA  
 180 Q Q T N N Q E P I K V A T L S T L L F K P A V I A D S G S Y F C T  
  
 701 GCCAAGGGCC AGGTGGCTC TGAGCAECAC AGGCACATTG TGAAGTTGT GGTCAAAGC TCCTCAAAGC CAAGACTGAG GCACCTACAA  
 CGGTTCCCGG TCCAACGAG ACTGGTGGT TCGCTGTAC ACTTCAACA CCAGTTTCTG AGGATTTTCG ATGAGTTCTG GTTCTGACTC CGTGGATGTT  
 213 A K G Q V G S E Q H S D I V K F V V K D S S K L L K T K T E A P T T  
  
 801 CCATGACATA CCGCTTGAAA GCAACATCTA CAGTGAAGCA GTCTGGGAC TGGACCACTG ACATGGATGG CTACCTTGA GAGACAGTG CTGGGCCAGG  
 GGTACTGTAT GGGGAACCTT CGTTGTAGAT GTCACTTGT CAGGACCTG ACCTGGTGAC TGTACCTACC GATGGAACCT CTCGTGTAC GACCCGGTCC  
 247 M T Y P L K A T S T V K Q S W D W T T D M D G Y L G E T S A G P G  
  
 901 AAAGAGCCTG CCGTCTTIG CCATCATCCT CATCATCTCC TTGTGCTGA TGGTGGTTT TACCATGGCC TATATCATGC TCTGTGGAA GACATCCCAA  
 TTCTCTGGAC GGACAGAAC GGTAGTAGGA GTAGTAGAGG AACACGACAT ACCACCAAAA ATGGTACCGG ATATAGTAGG AGACAGCCTT CTGTAGGGTT  
 280 K S L P V F A I I L I I S L C C M V V F T M A Y I M L C R K T S Q  
  
 1001 CAAGAGCATG TCTACGAAGC AGCCAGGGA CATGCCAGAG AGCCCAAAGA CTCTGGAGAA ACCATGAGGG TGGCATCTT CGCAAGTGGC TGCTCCAGTG  
 GTTCTGTAC AGATGCTTGG TCGGTCCCGT GTAOGTCTC TCGGTTGCT GAGACCTCTT TGGTACTCCC ACCGGTAGAA GGGTTACCGG ACGAGGTAC  
 313 Q E H V Y E A A R A H A R E A N D S G E T M R V A I F A S G C S S D  
  
 1101 ATGAGCCAAC TTCCAGAAT CTGGCCAACA ACTACTCTGA TGAGCCCTGC ATAGCACAGG AGTACCAGAT CATGGCCAG ATCAATGGCA ACTACGCCCG  
 TACTGGTTG AAGGGTCTTA GACCGTTGT TGATGAGACT ACTGGGAGG TATCTGTCC TCATGGTCTA GTAGCGGTC TAGTTACGT TGATCGGGCC  
 347 E P T S Q N L G N N Y S D E P C I G Q E Y Q I I A Q I N G N Y A R  
  
 1201 CCTGCTGGAC ACAGTCTCTC TGGATTATGA GTTCTGGCC ACTGAGGGA AAAGTGCTG TTAANAATGC CCAATTAGGC CAGGATCTGC TGACATAATC  
 GGACGACCTG TGTCAAGGAG ACCTAATACT CAAAGACCGG TGACTCCCGT TTTCACAGAC AATTTTACG GGGTAATCG GTCTAGACG ACTGTATTAG  
 380 L L D T V P L D Y E F L A T E G K S V C O  
  
 1301 TAGAGTCGAC CTGCAGAAGC TTGGCCGCCA TGGCCCACT TGTTATTGC ACCTTAAAT GGTTACAAT AA  
 ATCTCAGCTG GAAGTCTTGG AACGGGGGT ACCGGGTGA ACAATAAGS TCGAATATTA CCAATGTTTA TT

FIG. 1B

1 GTCCAACTGC ACCTGGTTC TATCGATAGG AGCCTGGAG AAAGGACAGA AGTAGCTCTG CCTGTGATGG GGAICTTACT GGGCCTGCTA CTCTGGGGC  
 CAGGTTGACG TGGAGCCAAG ATAGCTATCC TCGGACCTTC TTCTGTGCT TCATCGAGAC CGACACTACC CCTAGAAATGA CCGGACGAT GAGGACCCCG  
 1 M G I L L G L L L L G H  
 101 ACCTAACAGT GGACACTTAT GGCCTGCCA TCCTGGAAGT GCCAGAGAGT GTAACAGGAC CTTGAAAGG GGATGTGAAT CTTCCTCGCA CCTATGACCC  
 TGGATTGICA CCTGTGAATA CCGGCAGGT AGGACCTTCA CCGTCTCTCA CATTGTCTG GAACCTTTCC CCTACACTTA GAAGGACGT GGATACTGGG  
 13 L T V D T Y G R P I L E V P E S V T G P W K G D V N L P C T Y D P  
 201 CCTGCAAGC TACACCCAAG TCTTGGTGAA GTGGCTGGTA CAACGTGGCT CAGACCTGT CACCATCTTT CTAAGTGACT CTTCTGGAGA CCATATCCAG  
 GGACGTTCCG ATGTGGTTC AGAACCACTT CACCGACCAT GTTCGACCGA GTCTGGCACA GTGGTAGAAA GATGCACTGA GAAGACCTCT GGTATAGGTC  
 46 L Q G Y T Q V L V K W L V Q R G S D P V T I F L R D S S G D H I Q  
 301 CAGCAAAAGT ACCAGGCGC CCTGCATGTG AGCCACAAGG TTCAGGAGA TGTATCCCTC CAATTGAGCA CCCTGGAGAT GGATGACCGG AGCCACTACA  
 GTCCGTTTCA TGGTCCCGC GGAAGTACAC TGGTGTTC AACGTCTCT ACATAGGAG GTTAAGTGT GGGACCTCTA CCTACTGGC TCGGTGATGT  
 79 Q A K Y Q G R L H V S H K V P G D V S L Q L S T L E M D D R S H Y T  
 401 CGTGTGAAGT CACCTGGCAG ACTCCTGATG GCAACCAAGT CGTGAGAGT AAGATTACTG AGTCGGTGT CCAGAAACAC TCCTCAAAGC TACTCAAGAC  
 GGACACTTCA GTGGACCGTC TGAGGACTAC CGTTGGTTCA GCACTCTCTA TTCTAATGAC TCGAGGCACA GGTCTTTGTG AGGAGTTTCG ATGAGTTCTG  
 113 C E V T W Q T P D G N Q V V R D K I T E L R V Q K H S S K L L K T  
 501 CAAGACTGAG GCACCTACAA CCATGACATA CCCCCTTGAA GCAACATCTA CAGTGAAGCA GTCCTGGGAC TGGACCACTG ACATGGATGG CTACCTTGGA  
 GTTCTGACTC CGTGGATGTT GGTACTGTAT GGGGAACCTT CCGTGTAGAT GTCACTTGT CAGGACCTG ACCTGGTGAC TGTACCTACC GATGGAACCT  
 146 K T E A P T T M T Y P L K A T S T V K Q S W D W T T D M D G Y L G

\*insert begins here

**FIG. 2A**



601 GAGACCAGTG CTGGGCCAGG AAGAGCCCTG CCTGCTTTG CCATCATCCT CATCATCTCC TTGTGCTGTA TGGTGGTITT TACCATGGCC TATATCATGC  
 CTCTGGTCAC GACCCGGTCC TTCTCGGAC GGACAGAAAC GGTAGTAGGA GTAGTAGAGG AACACGACAT ACCACCAAAA ATGGTACCGG ATATAGTAGC  
 179 E T S A G P G K S L P V F A I I L I I S L C C M V V F T M A Y I M L  
  
 701 TCTGTGGAA GACATCCCAA CAAGAGCATG TCTACGAAGC AGCCAGGCA CATGCCAGAG AGGCCAAGCA CTCTGGAGAA ACCATGAGGG TGGCCATCTT  
 AGACAGCCTT CTGTAGGGTT GTTCTGTAC AGATGCTTGG TGGTCCCGT GTACGGTCTC TCGGTTGCT GAGACCTCTT TGGTACTCCC ACCCGTAGAA  
 213 C R K T S Q Q E H V Y E A A R A H A R E A N D S G E T M R V A I F  
  
 801 OGCAAGTGGC TGCTCCAGTG ATGAGCCAAC TTCCAGAAT CTGGGCAACA ACTACTCTGA TGAGCCCTGC ATAGSACAGG AGTACCAGAT CATGGCCCAG  
 GGGTTACCGG ACGAGGTCAC TACTCGGTTG AAGGGTCTTA GACCCGTTGT TGATGAGACT ACTCGGAGG TATCTGTGTC TCATGGTCTA GTAGCGGGTC  
 246 A S G C S S D E P T S Q N L G N N Y S D E P C I G Q E Y Q I I A Q  
  
 901 ATCAATGGCA ACTACGCCCG CCTGCTGGAC ACAGTTCTC TGGATTATGA GTTCTGCCC ACTGAGGCA AAGTGTCTG TTAATAATGC CCCATTAGGC  
 TAGTTACCGT TGATGCGGGC GGACGACCTG TGTCAGGAG ACCTAATACT CAAAGACCGG TGACTCCCGT TTTCACAGAC AATTTTACG GGGTAATCOG  
 279 I N G N Y A R L L D T V P L D Y E F L A T E G K S V C O  
  
 1001 CAGGATCTGC TGACATAATC TAGAGTCGAC CTGCAGAAGC TTGGCCGCCA TGGCCCAACT TGTTTATTGC AGCTTATAAT GGTACAATA  
 GTCTAGACG ACTGTATTAG ATCTCAGCTG GAGGCTTGG AACCGCGGT ACCGGTTGA ACAATAACG TCGAATATTA CCAATGTTAT

<sup>^</sup>insert ends here

**FIG. 2B**

1 GTCCAACTGC ACCTCGGTTCTATCGATTGCAATTGCGCCA CACTGGCCGG ATCCTCTAGA GATCCCTCGA CCTCGACCCA CCGGTCCGAG CAGCAAGAGG  
 CAGGTTGACG TGGAGCCAAG ATAGCTAAGC TTAAGCCGGT GTGACCGGCC TAGGAGATCT CTAGCGAGCT CGAGCTGGGT GCGCAGGCTC GTGTTCTCC

101 ATGGAAGGAT GAATAGAAGT AGCTTCAAT AGGATGGAGA TCTCATCAGG CTTGCTGTTCTGCGCCACC TAATAGTGCT CACCTATGGC CACCCCAACCC  
 TACCTTCCTA CTTATCTTCA TCGAAGTTTA TCCTACCTCT AGAGTAGTCC GAAGCACAAG GACCCGGTGG ATTATCAGGA GTGGATACCG GTGGGGTGGG  
 1 M E I S S G L L F L G H L I V L T Y G H P T L  
 \*MET

201 TAAAAACACC TGAGAGTGTG ACAGGGACCT GGAAGGAGA TGTGAAGATT CAGTGCATCT ATGATCCCT GAGAGGCTAC AGGCAAGTTT TGGTGAATG  
 ATTTTGTGG ACTCTCACAC TGTCCTGGA CCTTCTCT ACCTTCTAA GTCAGGTAGA TACTAGGGA CTCTCGATG TCGTTCAAA ACCACTTTAC  
 24 K T P E S V T G T W K G D V K I Q C I Y D P L R G Y R Q V L V K W

301 GCTGTAAGA CAGGCTCTG ACTCGTCCAC CATCTTCTA CGTGACTCCA CTGGAGACCA TATCCAGCAG GCAAAGTACA GAGGCCGCT GAAAGTGAGC  
 CGACCATTTCT GTCCCGAGAC TGAGGCAGTG GTAGAAGGAT GCACCTCGGT GACCTCTGGT ATAGTCTGT OGTTCATGT CTCGCGCGGA CTTTCACTCG  
 57 L V R H G S D S V T I F L R D S T G D H I Q Q A K Y R G R L K V S

401 CACAAAGTTC CAGGAGATGT GTCCCTCCAA ATAAATACC TGCAGATGA TGACAGGAAT CACTATACAT GTGAGGTAC CTGGCAGACT CCTGATGGAA  
 GTGTTTCAAG GTCTCTACA CAGGAGGTT TATTTATGG ACGTGACCT ACTGCTTGA GTGATATGA CACTCCAGTG GACCGTCTGA GGACTACCTT  
 90 H K V P G D V S L Q I N T L Q M D D R N H Y T C E V T W Q T P D G N

FIG. 3A

501 ACCAAGTAAT AAGAGATAAG ATCATTGAGC TCCTGTTCG GAAATATAAT CCACCTAGAA TCAATACTGA AGCACCTACA ACCCTGCACT CCTCTTTGGA  
 TGGTTCATTA TTCTCTATTC TAGTAACCTG AGGCACAAGC CTTTATATTA GGTGGATCTT AGTTATGACT TCGTGGATGT TGGGACGTGA GGAGAAACCT  
 124 Q V I R D K I I E L R V R K Y N P P R I N T E A P T T L H S S L E  
  
 601 AGCAACAACCT ATAATGAGTT CAACCTCTGA CTGTGACCACT AATGGGACTG GAAAACCTGA GGAGACCATT GCTGGTTCAG GGAGGAACCT GCCAATCTTT  
 TGGTTGTTGA TATTACTCAA GTTGGAGACT GAACTGGTGA TTACCCCTGAC CTTTGAACCT CCTCTGGTAA CGACCAAGTC CCTCCTTGA CGGTTAGAAA  
 157 A T T I M S S T S D L T T N G T G K L E E T I A G S G R N L P I F  
  
 701 GCCATAATCT TCATCATCTC CCTTTGCTGC ATAGTAGCTG TCACCATACC TTATATCTTG TTCCGCTGCA GGACATTCCA ACAAGAGTAT GTCTATGGAG  
 CGGTATTAGA AGTAGTAGAG GGAACGACG TATCATCGAC AGTGGTATGG AATATAGAAC AAGGGGACGT CCTGTAAAGT TGTTCATA CAGATACCTC  
 190 A I I F I I S L C C I V A V T I P Y I L F R C R T F Q Q E Y V Y G V  
  
 801 TGAGCAGGT GTTGGCCAGG AAGACAAGCA ACTCTGAAGA AACCACAAGG GTGACTACCA TCGCAACTGA TGAACCAGAT TCCGAGGCTC TGATTAGTGA  
 ACTGGTCCCA CAAACGGTCC TTCTGTGGT TGAGACTTCT TTGGTGTCC CACTGATGGT AGCGTTGACT ACTTGGTCTA AGGTCGGAG ACTAATCACT  
 224 S R V F A R K T S N S E E T T R V T T I A T D E P D S Q A L I S D  
  
 901 CTACTCTGAT GATCCTTGGC TCAGCCAGGA GTACCAATA ACCATCAGAT CAACAATGTC TATTCCTGCC TGCTGAACAC AGTTTCCAGA AACTAAGAAG  
 GATGAGACTA CTAGGAACGG AGTCGGTCTT CATGGTTTAT TGGTAGTCTA GTTGTACAG ATAGGACGG AGGACTTGTG TCAAAGGTCT TTGATTCTTC  
 257 Y S D D P C L S Q E Y Q I T I R S T M S I P A C O  
  
 1001 TTCTTGTCTAC TGAAGAAAAT AACATCTGCT AAAATGCCCC TACTAGTCA AGGTCTACTG GCGTAATTAC CTGTACTTA TTACTACTT GCCTTCAACA  
 AAGAACGATG ACTTCTTTTA TTGTAGACGA TTTTAAGGGG ATGATTACGT TCCAGATGAC CGCATTAAATG GACAATGAAT AAATGATGAA CCGAAGTTGT

FIG. 3B

1101 TAGCTTTCTC CCTGGCTTCC TTTCTTCTTA GACAACCTAA AGTATCTATC TAGTCTGCCA ATTCTGGGCG CATTGAGAAA TCCTGGGTTT GGCTAAGAAAT  
 ATCGAAAGAG GGACCGAAGG AAAGAAGAAT CTGTTGGATT TCATAGATAG ATCAGACGGT TAAGACCCCG GTAACTCTTT AGGACCCAAA CCGATTCTTA  
  
 1201 ATACTACATG CACCTCAAGA AATCTAGCTT CTGGCTTCA CCAGAACAA TTTTCTTCT CAACTCTTCT CCAAACAGCA GAGAAATTCC  
 TATGATGTAC GTGGAGTTCT TTAGATCGAA GACCGGAAGT GGGTCTTGTT AAAAGAAGGA TCCCGGAAGT GTTGACAAGA GGTTTGTGCT CTCCTTAAGG  
  
 1301 ATAGCAGTAG AGGTTCTTTA TCATGCCCTCC AGACAGCGTG AGTCTCAGTC CTACAAACTC AGACAAGCAC ATGGGTCTAG GATTACTCCT CTTTCTCTAG  
 TATGGTCATC TCCAAGAAAT AGTACGGAGG TCTGTCCGAC TCAGAGTCAG GATGTTGAG TCTGTTGCTG TACCCAGATC CTATGAGGA GAAAGAGATC  
  
 1401 GGCCAGATGA CTTTTAATTG ATATTACTAT TGCTACATTA TGAATCTAAT GCACATGTAT TCTTTTGTG TTAATAATG TTTAATCATG ACATCAAAAA  
 CCGGTCTACT GAAAAATTAAC TATAATGATA ACGATGTAAT ACTTAGATTA CGGTACATA AGAAACAAC AATTATTAC AAATTAGTAC TGTAGTTTTT  
  
 1501 AAAAAAAAAA AAGGGCGCGC GCGACTCTAG AGTGGACCTG CAGTAGGGAT AACAGGTAA TAAGCTGGC GCGCATGGC CAACTTGTTT  
 TTTTTTTTTT TTCCCGCCCG CCGTGAGATC TCAGCTGGAC GTATCCCTA TTGTCCCAT ATTGGAACCG GCGGTACCG GTTGAACAAA  
 ^pRK5 continues here

FIG. 3C

Structure-based affinity maturation of CRIg to generate a more potent inhibitor

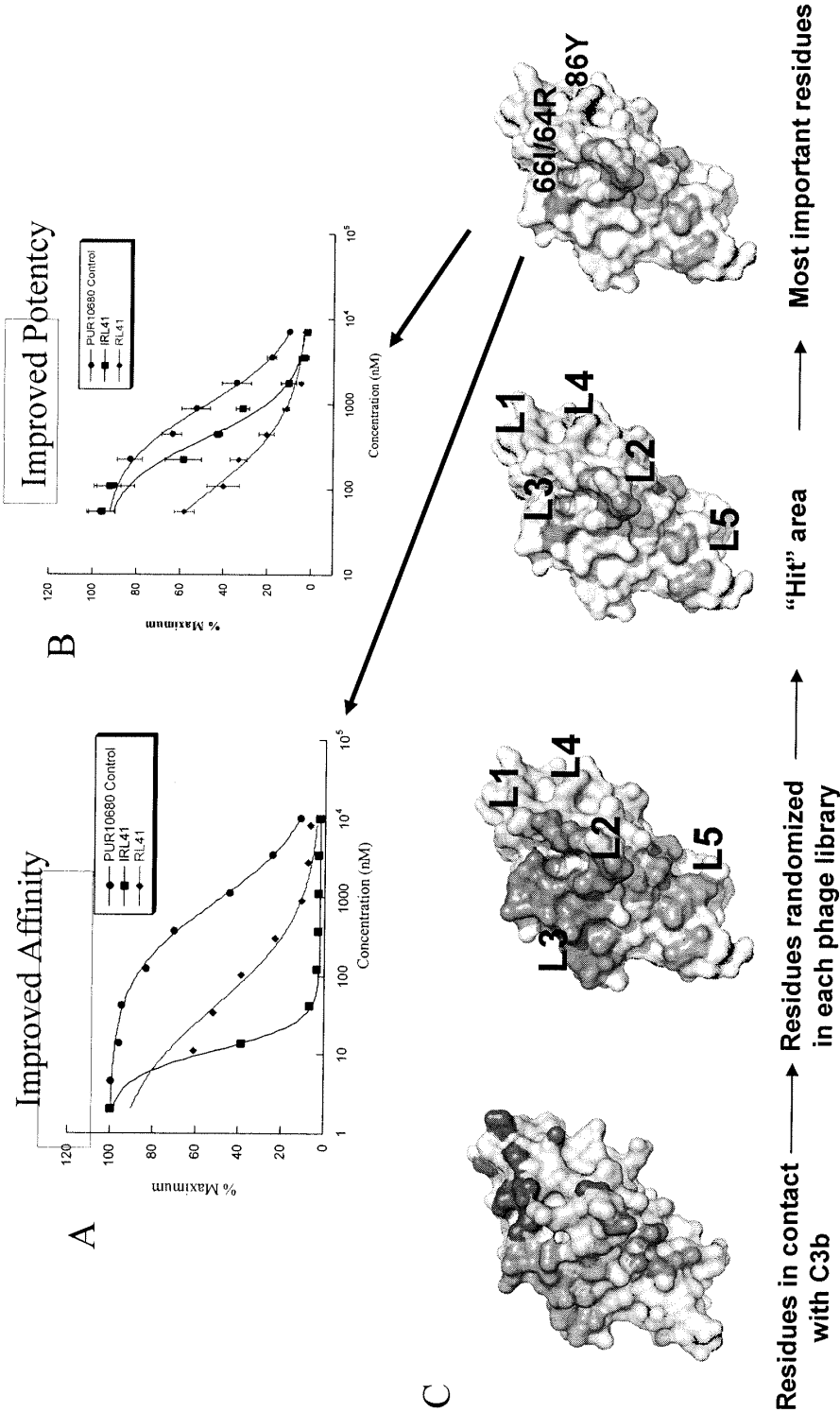
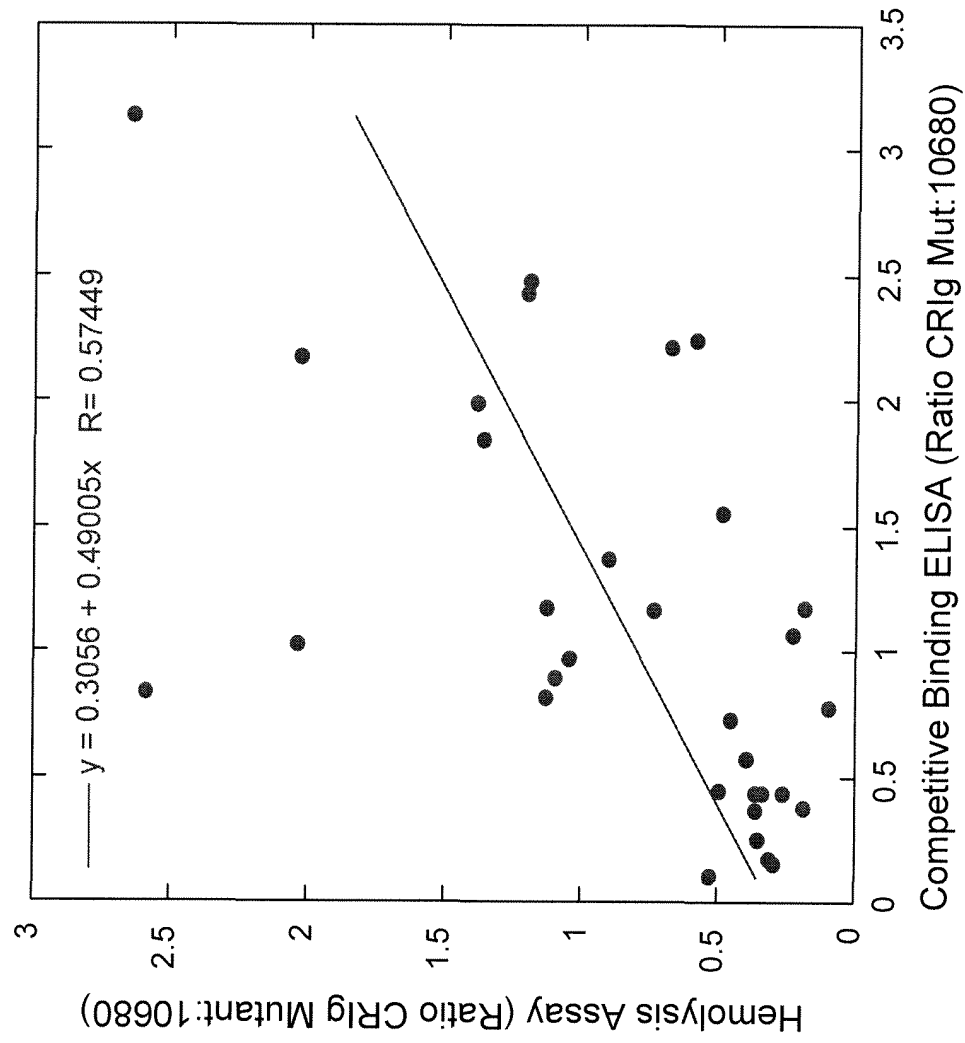


Fig. 4



The correlated between competitive ELISA and Hemolytic Assay

**Fig. 5**

*Improved affinity of the Q64R / M86Y  
CRlg mutant*

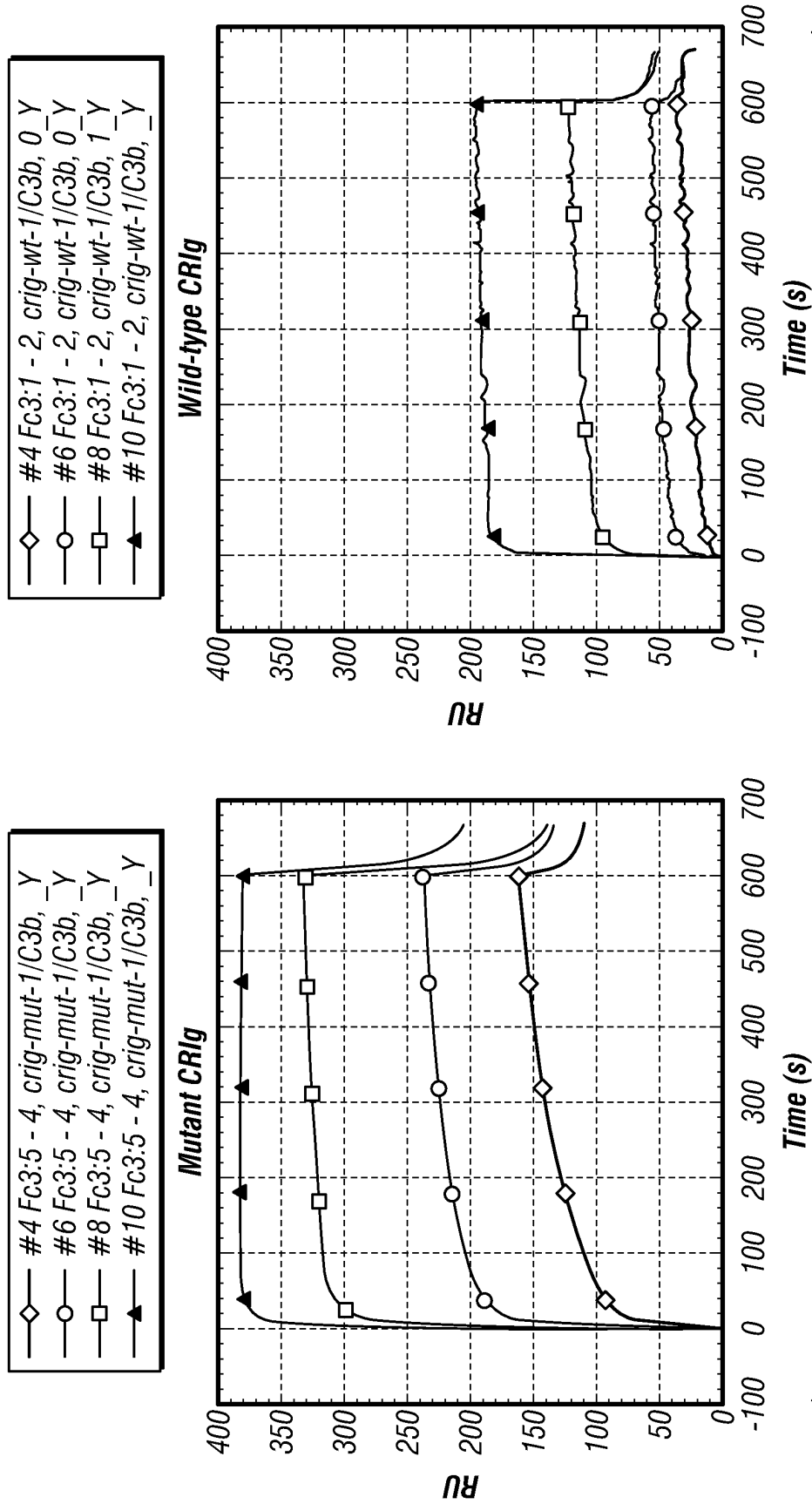
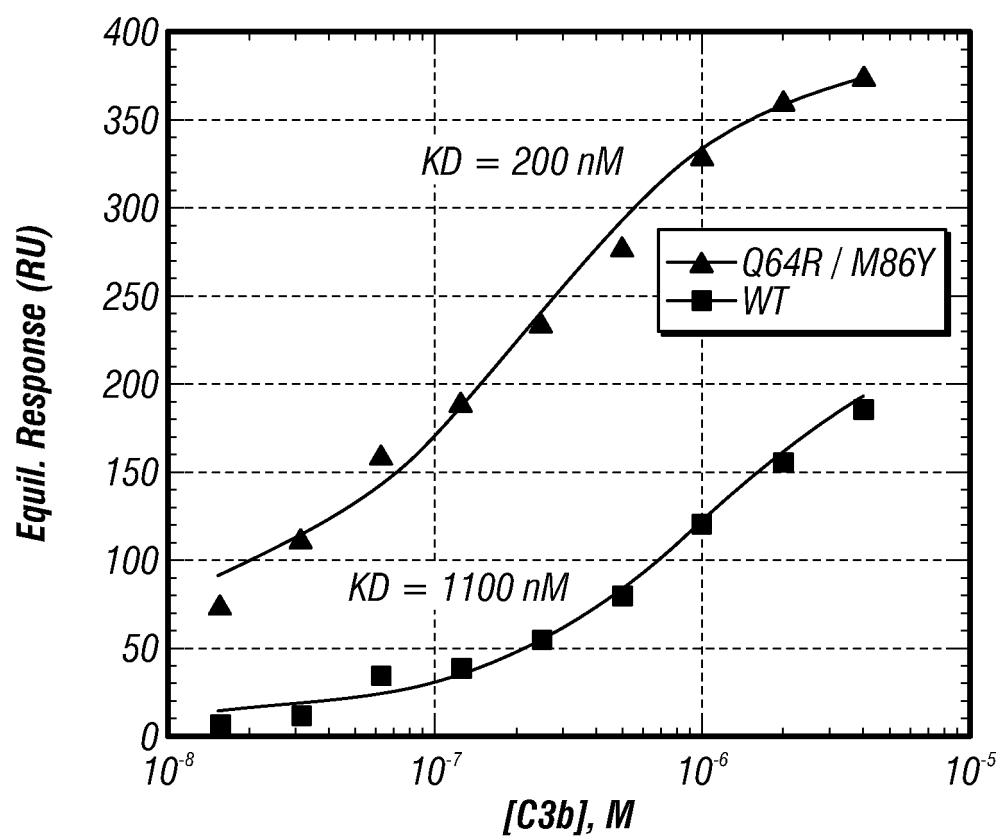


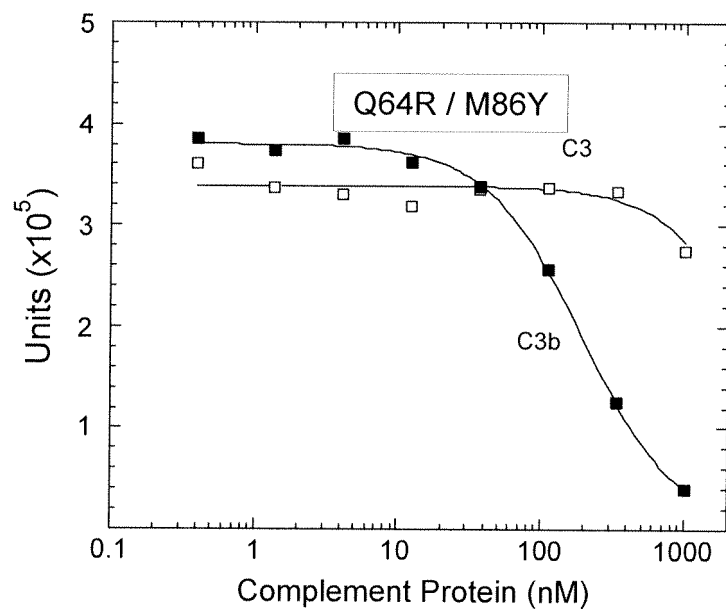
FIG. 6A

**Improved affinity of the Q64R / M86Y  
CRlg mutant**



**FIG. 6B**



**Affinity-improved CRIg remains selective for C3b****Fig. 7**

# Improved complement inhibitory potency of CRlg Q64R / M86Y *in vitro* compared to wildtype CRlg

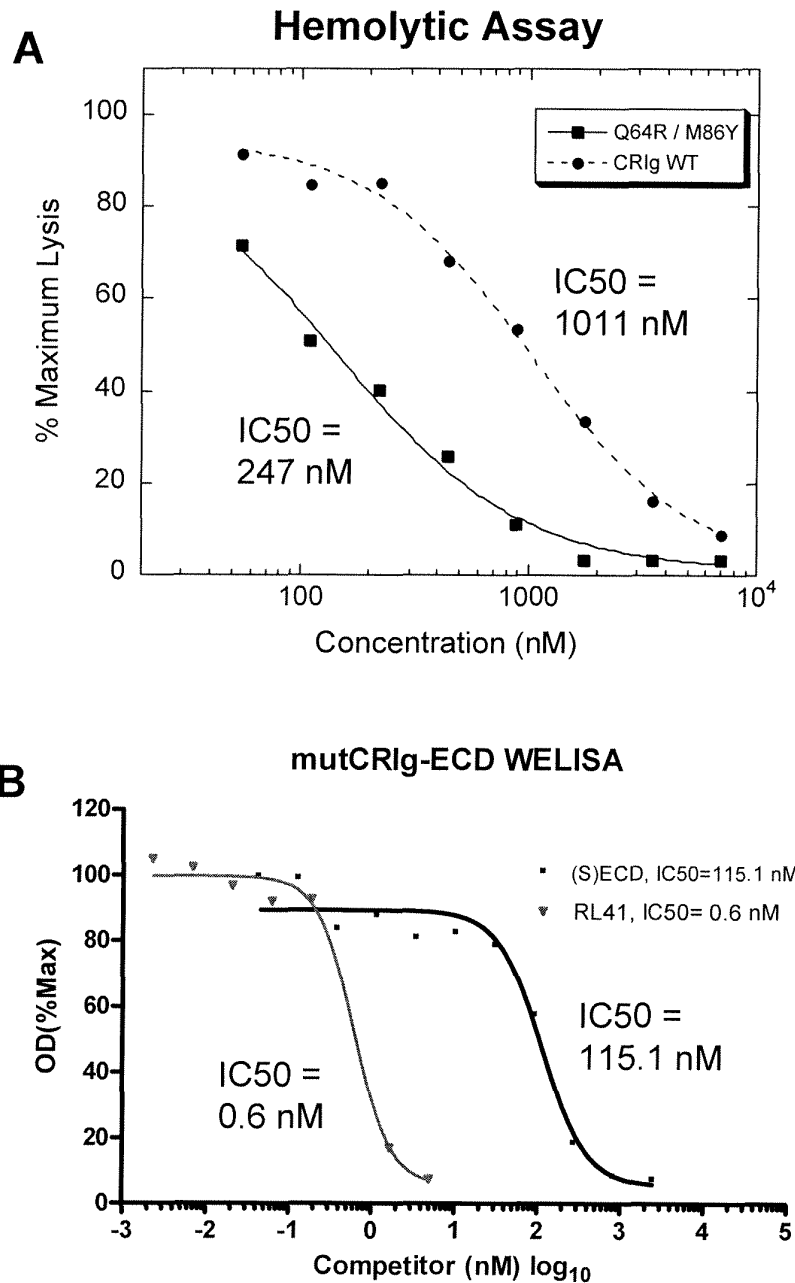
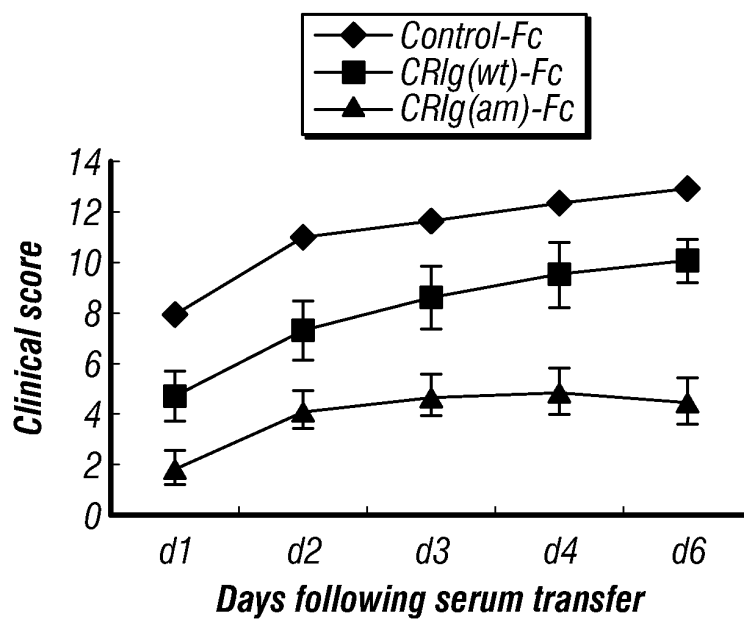
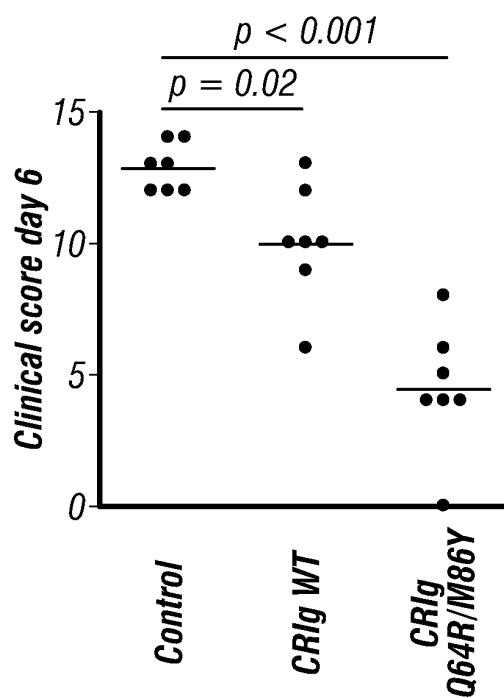


Fig. 8

***CRlg Q64R/M86Y shows improved efficacy  
in vivo over CRlg WT in vivo***

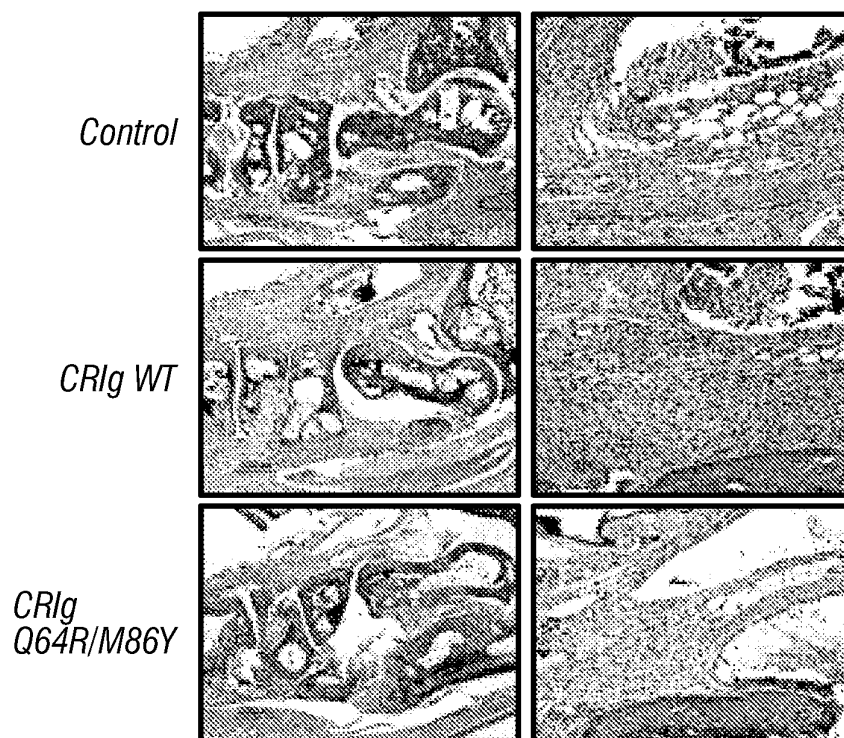


**FIG. 9A**

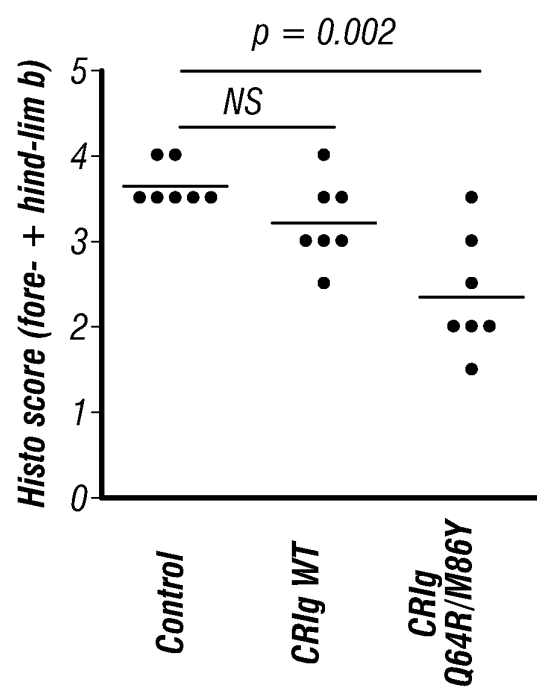


**FIG. 9B**

***CRIg Q64R/M86Y shows improved efficacy in vivo over CRIg WT in vivo***



**FIG. 9C**



**FIG. 9D**

**Table 1**

Table 1. Phage Libraries

Library	Position	Diversity
Library 1	E8-K15	$1.2 \times 10^{10}$
Library 2	R41-T47	$1.4 \times 10^{10}$
Library 3	S54-Q64	$1.6 \times 10^{10}$
Library 4	E85-Q99	$1.2 \times 10^{10}$
Library 5	Q105-K111	$1.9 \times 10^{10}$

# Step-wise generation of higher affinity CRlg by phage display

**Library 1**

Position	7	8	9	10	11	12	13	14	15	16
WT	P	E	S	V	T	G	P	W	K	G
	P	Y	S	V	T	G	P	W	K	G
	P	W	S	V	T	G	P	F	K	G
	P	Y	S	V	T	G	P	F	K	G
Consensus	P	Y	S	V	T	G	P	W	K	G

F

☐ Soft randomized

☒ Not randomized

☐ Selected

**Library 2**

Position	40	41	42	43	44	45	46	47	48	49	50	51	52	53
WT	Q	R	G	S	D	P	V	T	I	F	L	R	D	S
	Q	R	D	S	H	F	V	T	I	F	L	R	D	S
Consensus	Q	R	D	S	H	F	V	T	I	F	L	R	D	S

**Library 3**

Position	53	54	55	56	57	58	59	60	61	62	63	64	65
WT	S	S	G	D	H	I	Q	Q	A	K	Y	Q	G
	S	S	G	D	H	I	Q	I	A	K	Y	R	G
	S	S	G	D	H	I	Q	K	A	K	Y	Q	G
	S	S	G	D	H	I	Q	I	A	K	Y	Q	G
Consensus	S	S	G	D	H	I	Q	I	A	K	Y	R	G

Q

**Library 4**

Position	84	85	86	87	88	89	90	91	92	93	94	95	96	97	98	99	100
WT	L	E	M	D	D	R	S	H	Y	T	C	E	V	T	W	Q	T
	L	E	C	D	D	Q	S	H	Y	T	C	E	V	T	W	Y	T
	L	E	C	D	D	R	S	H	Y	T	C	E	V	T	W	R	T
	L	E	Y	D	D	R	S	H	Y	T	C	E	V	T	W	K	T
	L	E	Y	D	D	R	S	H	Y	T	C	E	V	T	W	K	T
	L	E	Y	D	D	R	S	H	Y	T	C	E	V	T	W	R	T
	L	E	Y	D	D	R	S	H	Y	T	C	E	V	T	W	L	T
	L	E	Y	D	D	R	S	H	Y	T	C	E	V	T	W	Q	T
	L	E	Y	D	D	K	S	H	Y	T	C	E	V	T	W	Q	T
	L	E	W	D	D	R	S	H	Y	T	C	E	V	T	W	F	T
	L	E	W	D	D	R	S	H	Y	T	C	E	V	T	W	Y	T
	L	E	W	D	D	R	S	H	Y	T	C	E	V	T	W	K	T
	L	E	W	D	D	R	S	H	Y	T	C	E	V	T	W	R	T
	L	E	W	D	D	R	S	H	Y	T	C	E	V	T	W	Q	T
	L	E	F	D	D	R	S	H	Y	T	C	E	V	T	W	K	T
	L	E	F	D	D	R	S	H	Y	T	C	E	V	T	W	R	T
Consensus	L	E	Y	D	D	R	S	H	Y	T	C	E	V	T	W	K	T

W  
F  
R

**Library 5**

Position	104	105	106	107	108	109	110	111
WT	N	Q	V	V	R	D	K	I
	N	R	V	V	R	D	N	I
	N	R	V	V	R	D	D	I
	N	R	V	V	R	D	Q	I
	N	R	V	I	R	D	Q	I
	N	R	V	I	R	D	H	I
	N	K	V	I	R	D	Q	I
	N	K	V	I	A	D	N	I
	N	K	V	I	S	D	N	I
	N	Q	V	I	R	S	D	I
	N	K	V	T	R	D	N	I
	N	K	V	V	R	D	Q	I
	N	K	V	V	R	D	N	I
	N	K	V	V	R	D	N	I
	N	K	V	V	R	D	D	I
	N	K	V	V	R	S	D	I
	N	K	V	V	S	D	D	I
Consensus	N	K	V	V	R	D	Q	I

R  
I  
D  
N

Each panel shows clones that were selected from each library based on binding affinity to C3b. The sequence is denoted by the single-letter amino acid code.

**Table 2**

Table 3

	Name	Mutants	Competitive ELISA			Hemolysis Inhibition		
			Mu Ic50 (nM)	WT-P10680 (nM)	WT/Mu	Mu Ic50	WT-P10680	WT/Mu
Library 1	L11	E8Y	384	332	0.9X	439	591	1X
	L12	E8W	142	332	2X	176	657	4X
	L13	W14F	882	332	0.4X	293	596	2X
	L15	E8Y/W14F	1274	332	0.3X	310	528	2X
Library 2	L21	G42D	453	332	0.7X	378	416	1X
	L22	D44H	338	332	1X	1207	591	0.5X
	L23	P45F	1266	332	0.3X	358	528	1.5X
	L24	G42D/D44H/P45F	238	332	1X	227	498	2X
Library 3	L31	Q60I	388	332	0.9X	78	416	5X
	L32	Q64R	34	332	10X	293	549	2X
	L33	Q60I/Q64R	255	332	1X	51	492	10X
Library 4	L41	M86Y	123	332	3X	124	657	5X
	L42	M86W	80	332	4X	226	635	3X
	L43	M86F	604	332	0.5X	185	794	4X
	L44	Q99K	268	332	1X	588	520	1X
	L45	Q99R	1397	331	0.2X	818	682	0.8X
	L46	Q99Y	468	332	0.7X	1715	663	0.4X
	L47	Q99F	296	332	1X	570	520	0.9X
	L48	Q99L	1376	332	0.2X	828	682	0.8X
	L49	M86W/Q99R	55	332	6X	201	635	3X
	L410	M86F/Q99R	121	332	3X	273	746	3X
	L411	M86W/Q99K	1594	298	0.2X	1980	747	0.4X
Library 5	L51	Q105R	599	298	0.5X	901	794	0.9X
	L52	Q105K	491	298	0.6X	696	663	1X
	L55	K110D	128	298	2X	196	525	3X
	L56	K110N	132	298	2X	376	746	1.2X
	L58	K110H	1105	298	0.3X	1393	686	0.5X
	L59	Q105R/K110N	127	298	2X	180	525	3X
	L510	Q105R/K110D	1011	298	0.3X	954	686	0.7X
	L511	Q105R/K110Q	166	298	2X	234	592	3X
	L512	Q105K/K110Q	937	298	0.3X	814	596	0.7X
	L514	Q105K/K110D	46	298	6X	167	549	3X

Table 4

Name	Mutants	Competitive ELISA		Hemolysis Inhibition	
		Mu Ic50 (nM) WT-P10680	(nM WT/Mu)	Mu Ic50 WT-P10680	WT/Mu
L12	E8W	142	332	2X	176
WL21	E8W/G42D	400	457	1X	1601
WL23	E8W/P45F	376	457	1X	2063
WL42	E8W/M86W	71	457	6X	416
WL51	E8W/Q105R/K110N	312	457	1X	475
WL55	E8W/K110N	374	457	1X	492
WL59	E8W/Q105R/K110N	276	457	12X	2340
L32	Q64R	34	332	10X	293
RL11	Q64R/E8Y	303	712	2X	390
RL21	Q64R/G42D	490	712	1X	217
RL23	Q64R/P45F	293	712	2X	375
RL41	Q64R/M86Y	40	712	18X	85
RL42	Q64R/M86W	56	712	13X	170
RL46	Q64R/Q99Y	682	712	1X	473
RL47	Q64R/Q99F	725	712	1X	669
RL49	Q64R/Q99R	64	712	11X	177
RL51	Q64R/Q105R/K110N	286	712	2X	227
RL52	Q64R/Q105K	290	712	3X	222
RL59	Q64R/Q105R/K110N	65	712	11X	208
L33	Q60I/Q64R	255	332	1X	51
IRL11	Q60I-Q64R/E8Y	34	903	27X	327
IRL21	Q60I-Q64R/G42D	29	903	31X	386
IRL23	Q60I-Q64R/P45F	31	903	29X	338
IRL24	Q60I-Q64R/G42D/D44H/P45F	4	903	226X	235
IRL41	Q60I-Q64R/M86Y	10	903	90X	358
IRL51	Q60I-Q64R/Q105R	24	903	38X	313
IRL52	Q60I-Q64R/Q105K	22	903	41X	143
IRL55	Q60I-Q64R/K110N	33	903	27X	292
IRL59	Q60I/Q105R/K110N	15	903	60X	277
L41	M86Y	123	332	3X	124
YL11	M86Y/E8Y	75	457	6X	562
YL21	M86Y/G42D/D44H/P45F	71	457	6X	220
YL23	M86Y/P45F	7	457	65X	202
YL24	M86Y/G42D/D44H/P45F	31	457	15X	248
YL44	M86Y/Q99K	91	457	5X	250
YL49	M86Y/Q99R	175	457	3X	392
YL51	M86Y/Q105R	39	457	12X	417
YL52	M86Y/Q105K	49	457	9X	224
YL59	M86Y/Q105R/K110N	18	457	25X	515



## REFERENCES CITED IN THE DESCRIPTION

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